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Dear reader

Welcome to the latest issue of CTI Mag!

Electric vehicles are steadily gaining ground, so far mainly in upmarket segments. But as the discussions at the recent CTI SYMPOSIUM Berlin showed, there is also a growing need for the “BEV for everybody”. In any case, OEMs and suppliers are permanently striving for efficient solutions, from single components to the whole system.

On the system level, Patrick Leteinturier, Infineon, expects an evolution to zonal and full-car computer architectures as he explains in our interview, affecting both E/E hardware and software. Magna presents a comprehensive system investigation of how all-wheel drive electrification can improve efficiency through “complementary” e-drive operation.

As to the e-drives, AAM discusses the challenges and solutions for high-speed e-motors. JJE introduces a two-speed electric beam axle for medium-duty truck applications, while Dana presents a highly integrated e-drive unit for multiple applications. Amsted Automotive report on a disconnect device for electric all-wheel drives, JTEKT Corp on their “ultra-compact products for further e-axle improvement”. Fluids supplier Infineum describes the cooling and lubrication requirements for heavy-duty e-drives. Finally, Konzelmann presents a novel pressure equalization solution for water crossing requirements.

Rounding off this issue, Thomas Hülshorst, FEV, discusses the differing battery requirements for EV and HEV applications, as well as the prospects for hybrid solid-state batteries.

All these ideas and solutions will contribute to making electromobility more attractive. Our thanks to everyone who helped to make this issue of CTI Mag happen. We wish you an interesting read!

Your CTI Magazine Team

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Interview

"Full Car Computer Could be a Reality by 2027"

Patrick Leteinturier

As electrification progresses, in-vehicle hardware and software architectures will evolve from distributed electronics to a "full car computer and zonal" model. We spoke with Patrick Leteinturier, Fellow Automotive Systems, Infineon Technologies, about these new architectures, new semiconductor materials, and the central role of "motion control".

Increasingly, vehicles are becoming software-defined. What does that mean for the way OEMs and Tier 1/2 suppliers cooperate?

Software-defined vehicle (SDV) is a disruptive step in the digital transformation of automobiles and even wider the complete mobility sector. In SDV, the software takes a major role and a part of it migrates from the endpoint electronic control units (ECU) to the aggregation and transformation layer, or even to the central car computer. That will lead to a change of ownership. The OEMs do write the software on a higher level, which should speed up development, but the endpoint software that controls the endpoint devices will still be delivered by a supplier. The way tasks are shared will change. Either way, both parties will need to collaborate more than in traditional architectures. We'll have to see who takes ownership of the development, integration, testing, and validation.

You foresee a change from distributed architectures and zone computers to Full Car Computer. When will that become a reality?

According to data from S&P Global Market Intelligence, Full Car Computer will have a market penetration of around 30% by 2034. The S-curve is starting now, and full adoption will take maybe 10 or 15 years to achieve. Practically all OEMs are working hard on this. For example, Volkswagen with Cariad. General Motors, Stellantis, and Ford are on it, and many others too. They're not all at the same stage, and they are not running at the same speed and solution. General Motors, for example, are fully committed and are putting their full power behind it. Some OEMs may have a full car computer as early as 2027.

How will the physical bus systems change with this migration?

The common understanding is that Ethernet-based communication will become much faster. There are some limitations with CAN. The Ethernet reaches from the endpoint to the aggregation and transformation layer; it will usually be 10BASE-T1S. Then from the zone controller to the central car computer, it will be fast Ethernet. Gigabit Ethernet is already in use, but now we are even talking about 50 Gbps. With CAN or LIN, we have some limiting factors. LIN is super low-cost and very simple, but end-to-end encrypted communication is almost impossible. It is not feasible for reprogrammable functions over the air, for example. If you want a more advanced endpoint, CAN could do that, but it would need some additional CANsec to enable security end-to-end. To simplify, it depends on the SOTA "software over the air" strategy from OEM to deploy the right physical bus.

When computing is centralized, what new challenges and opportunities could arise in terms of functional safety?

Today, we have a car with distributed electronics. But in the future, many functions will be synchronized on the central car computer layer. Take vehicle motion, for example. In terms of synchronization, this has the highest complexity. You have four wheels, each with just a few square centimeters of grip on the road. And via these small friction points, you control propulsion, regenerative braking, mechanical braking, steering, suspension, etc. When we apply e-motor power to each wheel, the propulsion can steer, brake, and propel. Of course, there will be more complexity in the way sensor and actuator information need to be handled and merged. We need a seamless OS platform, dependable electronics, new security, as well as fail-operational and redundancy concepts. But on the other hand, a centralized vehicle motion control setup, in conjunction with by-wire technology, also offers new opportunities. If one wheel fails, for example, the other three can compensate via all the integrated actuators, including the e-motors.

Let's talk about semiconductors: What materials will tomorrow's semiconductor materials use, and what are the benefits?

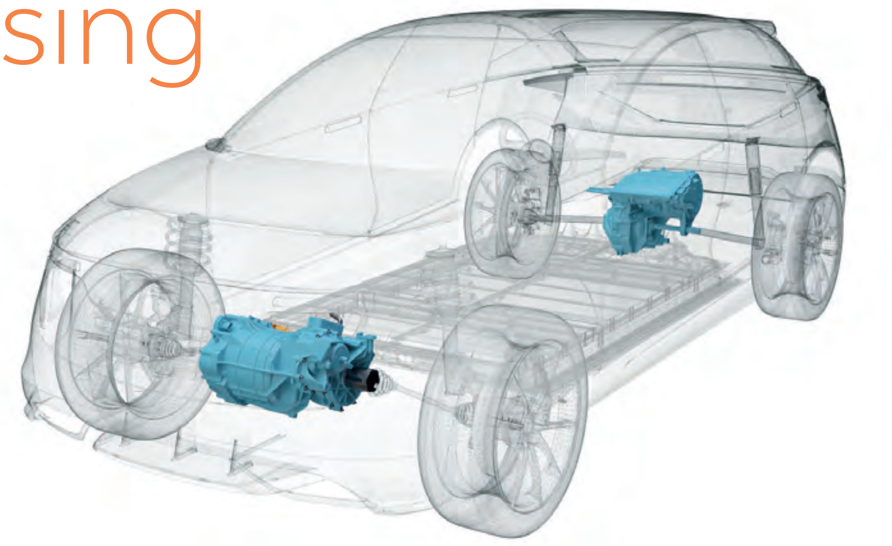
Firstly, SiC is a technology that was developed a long time ago for higher efficiency in solar and wind energy. We have been in volume production for a long time, and we have a lot of experience in manufacturing. We know all the figures for reliability and robustness. SiC is superior because it lets you reduce the internal resistance and the conduction losses of power electronics. And it's also quite good in terms of switching, so you have lower switching losses. This is extremely beneficial at part load. On the other hand, the material and its processing are rather expensive. However, we can blend SiC and IGBT (Insulated-Gate Bipolar Transistor). IGBT will work very efficiently at full load, and the silicon carbide will be used for part load. You could combine these properties across two axles – for example, IGBT at the rear and SiC at the front. But you can also combine them within the same power module, make a multiple die, and put them in parallel. This blend is much more efficient in both propulsion and regeneration and enables around 12% more range. On the other hand, the next technology GaN is already on the horizon and we are preparing that as well to be used in automotive applications and further increase efficiency to pay into decarbonization.

Semiconductors help to improve efficiency and range. But they are also part of a control system that requires a lot of energy. How can that be optimized?

That's a great question! People need to understand that we're not just talking about propulsion and regenerative braking. There are a lot of energy consumers, you still have to power up and supply a large number of electronic components. So you need to be very careful about your power mode, and your strategy for deciding whether an ECU needs to be on or off. Imagine you're at home, for example, and you hook your EV up to the charger. It's going to be plugged in for a long, long time… so gradually, even low energy consumption will add up to high consumption. So the aim is to only power the electronics you need. With a software-defined vehicle that is widely networked, you have to power the central computer, which consumes quite a lot of energy. On the other hand, it is also the 'brain' that handles power supplies vehicle-wide. Whether it's single zones, endpoints, or whatever, power consumption can be reduced or even switched off. So if my battery capacity runs low while I'm driving, for instance, I could switch off the cabin air conditioning or heating. The good thing about the car computer is that it has all the data to make the most efficient decisions. So yes, a central computer does consume energy. But more importantly, it's an enabler for intelligent energy and load management.

Interview: Gernot Goppelt

Increasing BEV Performance without Compromising Efficiency



Dr. Jörg Gindele, Senior Director

Business Expansion & Transformation, Magna Powertrain

Other than combustion engines, electric motors benefit from up- instead of downsizing. When intelligently combining them in an all-wheel drive, efficiency can be further increased, and especially by implementing a 'complementary' e-drive topology.

With combustion engines, we have become accustomed to the idea that downsizing concepts with increased engine load can help to reduce fuel consumption. In contrast, electric motors usually work most efficiently at partial loads. This is one reason why seemingly overpowered e-drives can be even more efficient. This applies even more when combining the e-drives over two axles in an electric all-wheel drive system (eAWD). When intelligently combining the efficiency maps of both motors and adding a decoupling option, eAWD can even be superior to a two-wheel drive system. The formula uses three levers: powerful e-motors, a decoupling system, and a 'complementary' e-drive combination.

Magna examined six in-house e-drives from 105 to 250 kW to examine the effect of increasing the power. It could be found, that while losses from the inverter and the gearbox vary only slightly, the e-motor losses become significantly smaller with increased output. The comparison was made with identical boundary conditions, i.e. 800 V architecture, SiC inverters, and the simulation performed in the WLTC.

Losses of electric drives

Comparing these six drives resulted in the findings illustrated in Figure 1: The inverter losses remained largely constant for all variants. The data showed somewhat greater differences in the transmission losses. The losses increase slightly with higher available maximum torque of the drive, but on the other hand, the more powerful motors allow for transmissions with longer ratios and thus reduced losses.

It is particularly noticeable that with increasing motor power, the e-drives have lower motor losses in the WLTC. This is because they can operate in a more efficient map range to handle the load. In simple terms, many e-motors have their best load points at around 30 percent of the load, while internal combustion engines often have their sweet spot at around 70 percent.

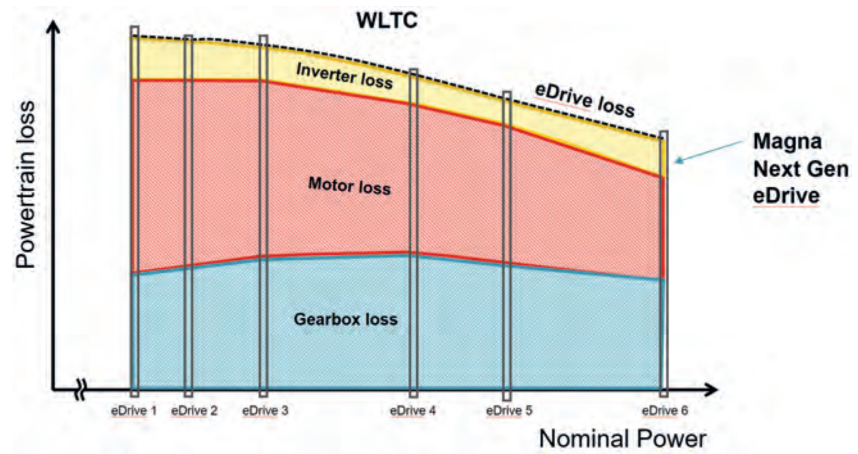


Figure 1: E-motor losses within the powertrain become smaller when increasing power output.

This means effectively that electric drives need no load point up-shifting in the familiar sense. On the contrary, the aim will be to bring the low-load efficiency sweet spot into congruence with typical operating points in the WLTC and real traffic situations like motorway driving.

Shifting the efficiency map of e-motors

To illustrate this, the efficiency-optimized operating range of the e-drive and the relevant operating points are shown in raltion to e-drive axle speed and axle torque, Figure 2. The relevant operating points are derived from the WLTC – and supplemented by highway driving since this can include higher speeds, especially in Germany.

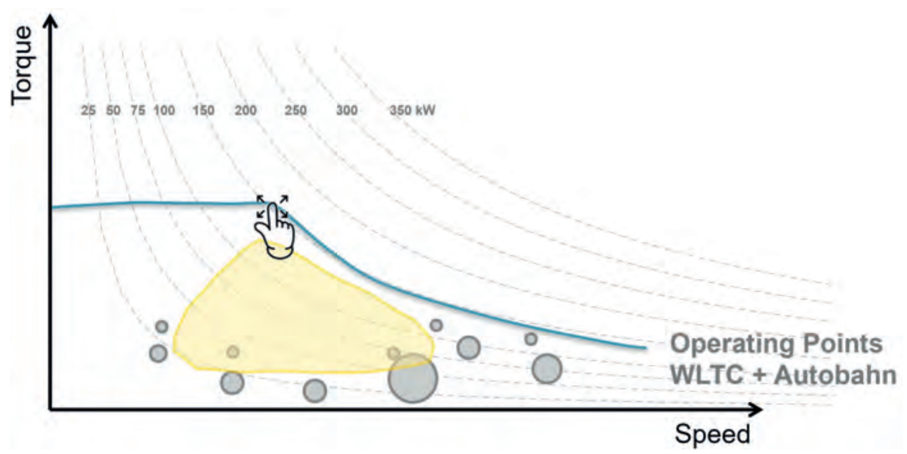


Figure 2: Typical offset of efficiency map and operating points with a small e-motor

The e-drive output torque is plotted on the y-axis, and the output speed is on the x-axis. The blue line indicates the peak torque curve including the corner point, which defines the maximum torque and power. The area in which the efficiency of the motor is at least 92% is shown in yellow. The grey circles indicate typical operating points in the WLTC and during highway driving, their diameter indicates the frequency of use. It is important to note that operating points at higher speed and higher torque are particularly significant as they result in increased losses.

The diagram illustrates an electric motor with a rather low power output. As can be seen, the operating points largely do not match the beneficial efficiency range. This especially applies to the operating points at higher speed and with a high frequency of use and thus a high effect on energy consumption. The aim is therefore to shift the sweet spot towards these points.

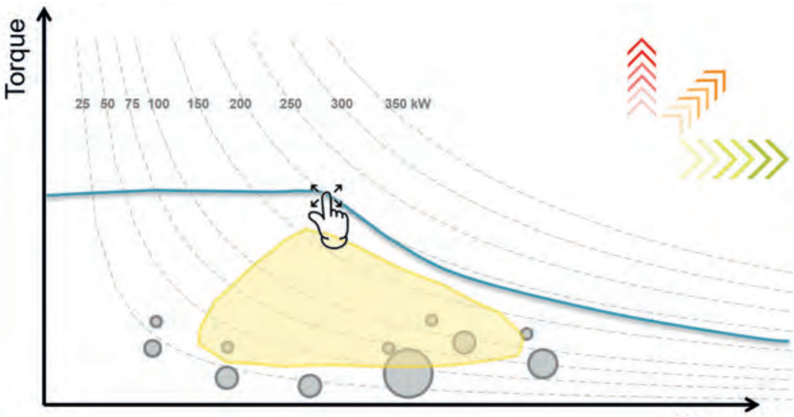


Figure 3: Stretching the efficiency map through motor speed improves the overlap

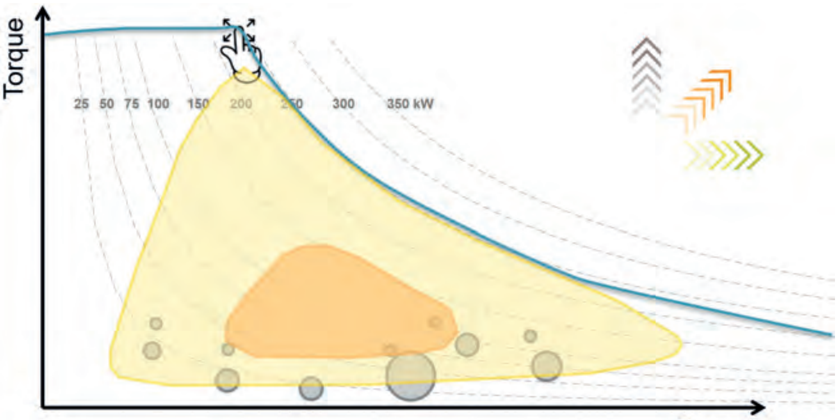


Figure 4: The up-scaled real motor shows even greater efficiency benefits.

If you now increase the power by increasing the torque while maintaining the motor speed, the sweet spot moves away from the operatin points. If, on the other hand, the power is increased via a moderate torque increase and increasing the motor speed, the sweet spot includes more operating points, especially at higher speeds. Even better coverage can be achieved if the power increase is made only via the speed so that the sweet spot includes a large part of the operating points, Figure 3.

In general, it can be seen that a larger sweet spot and thus better coverage with the operating points can be achieved with the more powerful motor. To which extent increasing the power by torque and/or speed is the best way, requires a specific look into the vehicle application and the electric motors available. There is always a specific trade-off between torque and speed.

Interestingly, it could also be seen for real-world e-motors that, when power is increased, the peak efficiencies continue to increase due to component effects. Electric motors designed for higher power output contain more copper and laminated iron materials. This results in a reduction of losses in the partial load range, Figure 4. Even with a power increase by more torque, the important operating points in the cycle and on the highway can be covered.

What this means for eAWD architectures

When scaling the range of BEVs, more electric power is necessary, because the batteries add considerable weight. It makes sense to distribute this power over two axles, the more so as this will improve traction and driving dynamics. However, as will be shown further below, an even higher efficiency can be achieved than with a 2WD vehicle through an intelligent "complementary" use of both primary and secondary of the eAWD system.

Figure 5 shows all the drive configurations investigated. The topologies range from 2WD to non-optimized AWD solutions, to those further optimized by decoupling systems, and finally to complementary drive designs.

First, two 2WD drives with 120 and 176 kW are shown on the left. The above drive in each column has a SiC inverter, enabling a powertrain efficiency improvement of approx. 2%. It can be seen in the second column that, contrary to "traditional" thinking, the more powerful drive offers higher efficiency.

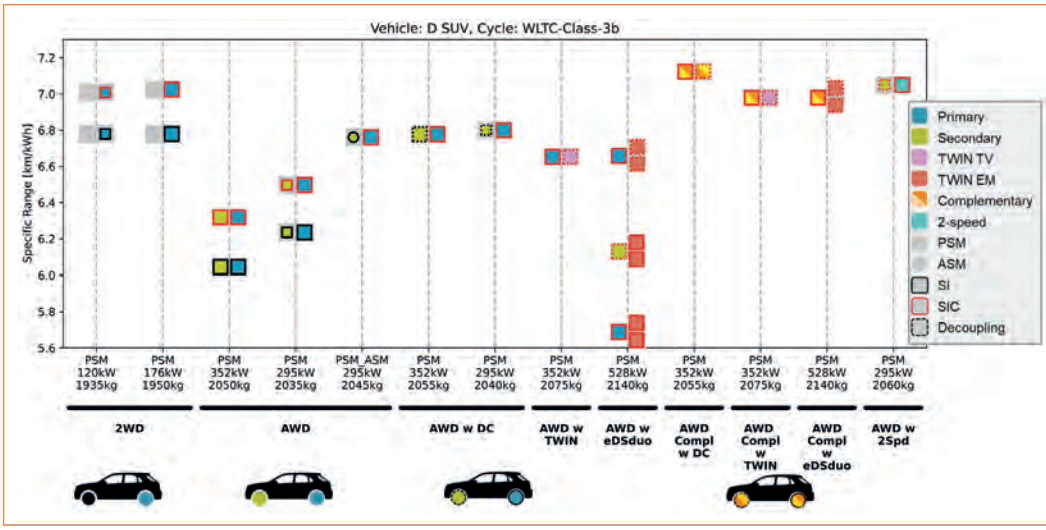


Figure 5: Efficiency results of the drivetrain configuration compared

Following on the right, only AWD architectures are shown. As expected, a configuration with two PSMs on the front and rear axles has increased losses. This is because the PSM cannot be deactivated, and is causing electrical losses. Both e-motors must work together permanently, restricting the operating strategy design.

A quite common solution is using a secondary axle with an ASM and a PSM at the primary axle. Magna Powertrain's ASM secondary drives are optimized for minimal drag losses through the implementation of a sophisticated bearing concept, resulting in low mechanical losses during standby operation. The ASM is only used as a boost axle here; the PSM primary drive can be designed for optimum efficiency in low-load situations.

Two PSM solutions with mechanical decoupling

Another option is to use a PSM with a mechanical decoupling device instead of an ASM on the secondary axis. In the Magna decoupling system, a lossless dog clutch is utilized to decouple the PSM. The switching times are so short that the system can be integrated into the operating strategy transparently and without any functional disadvantages [2].

Moreover, Magna has looked at the following secondary drives for AWD architectures: The Twin EM axle system uses two electric motors with summed up power, again with two decoupling elements. This allows for lateral torque vectoring and lossless decoupling, too. However, the available torque for torque vectoring is lower than with a single motor with a downstream torque vectoring element.

Magna Powertrain's Twin TV (Torque-Vectoring) drive operates with only one electric motor but features two wet clutches for lateral torque distribution. The (normally) open state of the clutches corresponds functionally to the decoupling function as described above. Drag losses of the clutch system are minimal thanks to increased air gaps and oil ejection. Compared to the variant with two motors, the advantage of this solution is that the torque of the single motor can be shifted entirely. Moreover, it is comparatively cost-effective.

Further benefits through complementary drives

When comparing the AWD variants described above, it can be seen that they are all close to an optimized 2WD drive in terms of efficiency. This confirms the assumption that AWD is preferable, as it comes with additional functional benefits. So far, however, this effect is mainly dominated by the higher power output and the resulting load reduction.

Complementary drives will enable a further efficiency increase. The concept of a complementary drive includes the integration of two distinct electric drives, each having unique advantages. One approach

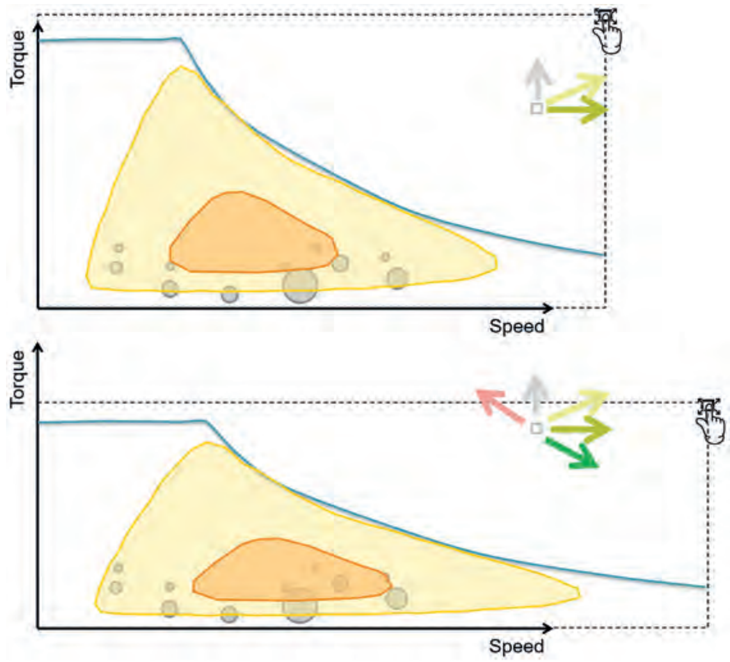


Figure 6: A longer ratio enables to improve the coverage of sweet spot and operating points.

to realizing the concept of complementary drives is combining a front axle with a long gear ratio and a rear axle that can be decoupled. The front axle's gear ratio is selected to cover the efficiency-optimized range for relevant highway operating conditions. Figure 6. As a result, the front axle exclusively handles constant highway driving.

Dynamic driving in the lower speed range is performed using both axles to maintain low load points. The e-motors are specifically optimized for these operating points to fully utilize the efficiency potential. The resulting reduced wheel torque of the front axle is compensated for by the second drive, which is dominant for wheel torque and traction when boosting (the secondary drive is located on the rear axle).

The savings are achieved in operating phases that are relevant for consumption, i.e., at constant speed, which is usually associated with more distance traveled. All three AWD variants considered in the complementary design even exceed 2WD efficiency by 2-3%. Which of the variants is preferable, mainly depends on functional requirements.

The overall result is that an intelligently designed complementary AWD is significantly more efficient than a 2WD drive, while including significantly increased customer benefits in terms of traction, driving dynamics, and vehicle controllability.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Unlocking the Key to Seamless EV Driveline Disconnects

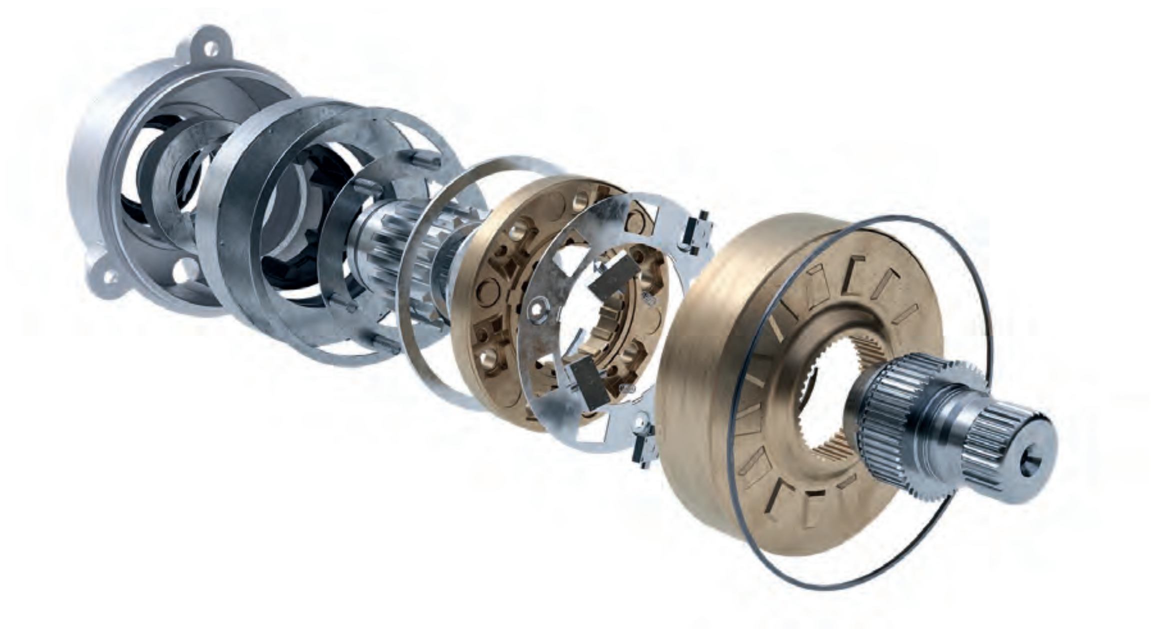
John Jennings, Director of Innovation and eMobility, Amsted Automotive

The future of vehicle propulsion is not simply a trending topic. It's a global reckoning, as well as a global opportunity for revolutionary advances in powertrain and driveline technologies. Next-generation technology is at the forefront, and leading the way is Amsted Automotive with its Dynamic Controllable Clutch (DCC), an Electro-Mechanical E-axle Disconnect system for EVs.

As you read in every issue of CTI Magazine, Electric Vehicles (EV) drivetrain systems are being redefined—creating next-generation propulsion systems—as the EV market grows rapidly. The first EV propulsion systems simply replaced ICE powertrains with electric motors and battery systems. This next generation of EV propulsion systems will need to be further optimized for function, efficiency, range and cost as the EV market scales up. This includes the need for new solutions to facilitate seamless eAWD disconnect with the ability to quickly and reliably shift between disconnected, forward propulsion, and regen or reverse modes. Design flexibility is also required for adaptability at multiple locations between the eMachine and wheels.

In addition to disconnects, next generation EV drivetrains will also require more sophisticated solutions for electronic park-lock, hill-hold and multi-speed shifting, combining the functions of historical ICE transmissions and drivelines. These technologies can be applied to EV passenger cars, light truck and commercial vehicles.

Means, an Amsted Automotive division, has developed controllable disconnect clutch and actuation technology with full disconnect and locking functions, plus the additional functionality for controlled bi-directional one-way-clutch operation. This technology, when applied to EV drivetrains, can provide novel and flexible system solutions for EV disconnects for both eAWD and primary electric drive unit (EDU) applications. The control and flexibility of this technology can also enable the same disconnect function and advantages for the primary EDU. Additional capability can also be combined with multi- speed shift functions, hill-hold and park-lock features to create novel multi-functional clutch solutions for the next generation of EV drivetrains. The first Means base disconnect for EV application was launched into production in 2021.



The Dawn of New Technology for EV Drivetrains

Market growth for EVs is exploding at a remarkable pace. Yet there's a significant challenge: OEMs and Tier 1 Automotive Suppliers – both established and new – may not have the capabilities to develop next-generation technology required for electrification. Simply put, traditional ICE drivetrains and electric drivetrains are not the same. Without this ability to adapt to the unique requirements of EV powertrain systems, there may be missed opportunities for new success within the transportation sector.

As emerging products for EV propulsion systems continue to be redefined and reinvented, Amsted Automotive is the leader in the solutions for EV drivetrains, optimizing for function, efficiency, range, and cost, as well as to meet emissions standards and other electrification targets. Means Industries, an Amsted Automotive company, has developed a novel multifunctional clutch technology that's revolutionizing electrification in a very short time: Dynamic Controllable Clutch (DCC) and Electro- Mechanical E-axle Disconnect Solutions.

Design and engineering expertise, as well as agile capabilities in advanced metal-forming and powder metal manufacturing with electro-mechanical clutch design capabilities for electrified propulsion solutions, have put Amsted Automotive at the forefront of advanced EV drivetrain technology worldwide.

ICE AWD Architecture

A typical ICE AWD architecture based on a front- wheel-drive platform includes an engine, a power- takeoff unit (PTU) in the transaxle and a rear-drive unit (RDU) with a coupler. The system has a disconnect in both the PTU and RDU.

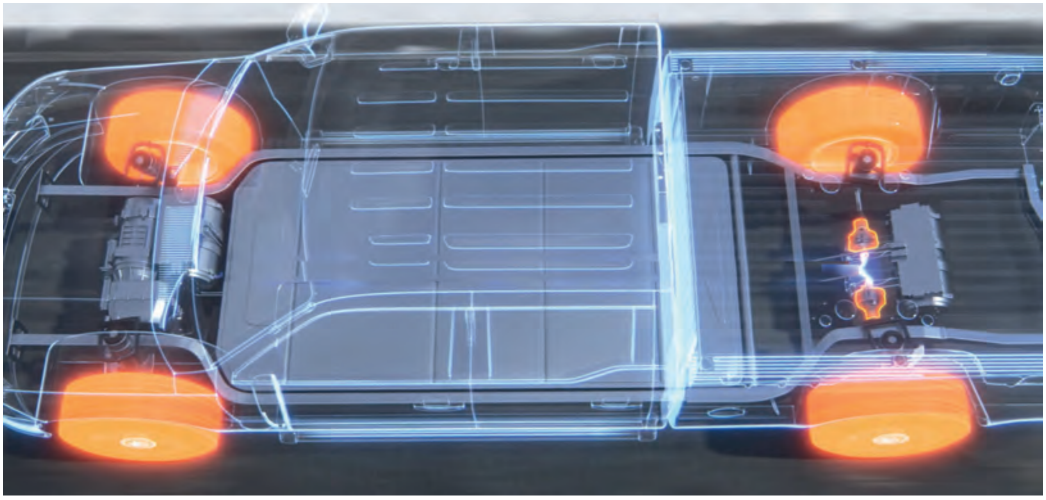
This configuration has parasitic losses created by hypoid gear meshing in both the PTU and RDU, fluid churning, bearing and seal drag, and spin loss of the propshaft. In addition to parasitic losses, there are challenges with seamless disconnect and reconnect of the RDU while the vehicle is in motion. The system must match rear-wheel speed with the ICE powertrain.

There is high inertial torque of the RDU. There are also challenges with cold-weather drag, block shift, and shift interruption with dog clutches and limitations on shift engagement time. Finally, by design, disconnect function must be contained in both the PTU and RDU, which poses challenges with packaging.

EV AWD Architecture

EV powertrains provide an opportunity to rethink the traditional AWD architecture. Without the need to physically connect the front and rear drive axles, parasitic losses can be significantly reduced, and packaging issue are simplified. EVs have a dedicated eMotor for each axle, or in some cases a dedicated eMotor for each wheel. This enables the eMotor to control the power and speed directly for each axle, and therefore it can also be used to manage the synchronization and speed-matching for the AWD disconnect & re-connect.

Advantages include flexible package locations for EV drivetrains and intelligent energy management to optimize driving range. The challenges in an EV AWD architecture are NVH – EVs do not mask NVH like ICE powertrains do – and managing AWD regenerative braking mode. All of this creates opportunity for new approaches to disconnect systems that cannot be accomplished with ICE AWD architectures.



The New EV AWD Disconnect Solution

At the 2018 CTI Symposium in Berlin, Means Industries redefined propulsion system design by introducing two game-changing technologies.

The Electronic Controllable Mechanical Diode (eCMD) is a static, electrically actuated concept that offered the benefits of latching in state without a constant power supply. Hydraulic control was eliminated as were the associated costs and complexities. Power would be consumed only during state transition, thereby reducing energy consumption.

The other new device was DCC. This was a level of advanced technology never before seen in electrified vehicles. Using electric actuation, DCC creates substantial packaging and system efficiencies by eliminating complex hydraulic systems. The dynamic controllable clutch technology coupled with electromagnetic actuation technology can be utilized in single or multi-speed gearboxes for markedly improved EV powertrain efficiencies. There was no need for more packaging space.

The DCC system offers fast, smooth shifting that is managed by eMotor controls, with mechanical engagement always available for eMotor speed matching. It is also very reliable; no blocked shifts. There are no friction elements during a mechanical engagement, with a bistable magnetic latch (on/off) to eliminate power consumption while in-state.

Benefits

- Blocked or rejected shifts are not possible
- Simplified system controls and reduces failure modes compared to traditional dog clutch
- Technology thoughtfully developed and easy to apply, calibrate, and use
- 5–10% increased vehicle range
- Up to 60 kg battery mass reduction opportunity

Performance

- Response Time
  - Full travel response time: 17ms
- Ease of Use
  - No block or rejected shifts are possible
  - Requires less control effort to synchronize state changes (On / Off)
- Energy Consumption
  - Bi-Stable Magnetic latch for ON/OFF positions
  - No power consumption while in-state
  - Magnetically latches even with power loss
- Torque
- 2,800+ Nm operating torque (8,000 Nm min. ultimate)
- Torque can be scaled as needed

Next-Gen EV Disconnect with One-Way Clutch Functionality

In order to enable faster AWD vehicle system disconnect shift time, the next generation EV disconnect includes another Amsted Automotive innovation: integrated one-way-clutch (OWC) functionality. This is easy to conceptualize by considering a bicycle. With power applied (pedaling), the one-way clutch transmits torque to the wheel.

When power is off (coasting and not pedaling), the one-way clutch overruns or freewheels. When power is reapplied (pedaling again), the pedals ramps up to match the wheel speed and then transmits torque again to the wheel.

Means developed an integrated controllable bi- directional one-way clutch which enables Reverse and regenerative braking. The system also includes a passive one-way clutch for forward driving operation. In freewheel mode, both clutches are disengaged.

Under power traveling forward, the passive one-way clutch engages to transmit torque to the wheels. When Reverse or regenerative braking mode are required, the controllable one-way clutch is engaged along with the passive one-way clutch.

In the forward propulsion direction, the disconnect and re-connect are automatic and is simply controlled by powering the propulsion motor on and off, just like described in the bicycle analogy.

This technology provides fast shift times – 17 millisecond pre-engagement shifts – for Reverse and regenerative braking. The system is based on proven production technology and is reliable. It eliminates the possibility of blocked shifts or rejected shifts. Mechanical engagement is always available for speed matching the eMotor. It offers the opportunity for flexible EV drivetrain packaging locations by providing modular style and integrated solutions.

And it can improve the efficiency of AWD EVs by as much as 5–10% on the highway because there are no friction elements and the magnetic latching for on/off states doesn't require any power consumption to remain in state.

The Next Generation is Here Now

With the accelerated push to rapidly grow the EV market, there may be more innovations in power-train being developed today than any other time in history. One of the key technologies developed by Means Industries for this market presents great opportunity to solve the issue of seamless eAWD disconnects in EV powertrains and provide much more. The design provides the ability to quickly and reliably shift between disconnected, forward propulsion, and regen or reverse modes. However, the design also enables flexibility for adaptability at multiple locations between the eMachine and wheels. Beyond the driving functions of an eAxle disconnect, the system also enables responsibilities previously provided by traditional ICE transmissions and drivelines such as park-lock, hill-hold and multi-speed shifting. The next generation of EV power-train systems is here today.

Who is Amsted Automotive?

Amsted Industries is a diversified designer and manufacturer of cutting-edge industrial solutions serving the railroad, vehicular and construction markets with a global foot-print spanning 66 facilities in 10 countries across 6 continents, with more than 19,000 employees and approximately $4B in annual revenue.

Amsted Automotive was formed in 2021 – bringing together two of its century-old, core Tier 1 and Tier 2 automotive supply business units – Means Industries and Burgess Norton, to form a new and innovative technology team. SMW Manufacturing was added to the group in 2021. The integration provides an expanded global presence with 16 facilities in North America, Asia and Europe to serve global automakers with a robust manufacturing footprint producing more than 100 million components and assemblies annually.

This group combines design and engineering expertise, strategically aligned to be a nimble leader in advanced metal-forming including powder metal manufacturing with electro-mechanical clutch design capabilities for electrified propulsion solutions, building on integral roles in global advanced automatic transmissions designed in North America, Europe, and Asia.

eFluid Formulation Balance & Challenges in Electrified Commercial Vehicles

Andrew Wood, Driveline Fluids Technologist, Infineum UK Ltd

Calum Sugden, Driveline Fluids Technologist, Infineum UK Ltd

The transportation industry is working to decarbonise, and commercial vehicle manufacturers are exploring a range of low and zero carbon propulsion options, including electrification.

New opportunities to formulate tailored driveline eFluids are emerging, as the electrified truck and bus market develops. The evolving electric drive architectures used in this vehicle segment have specific protection and performance needs.

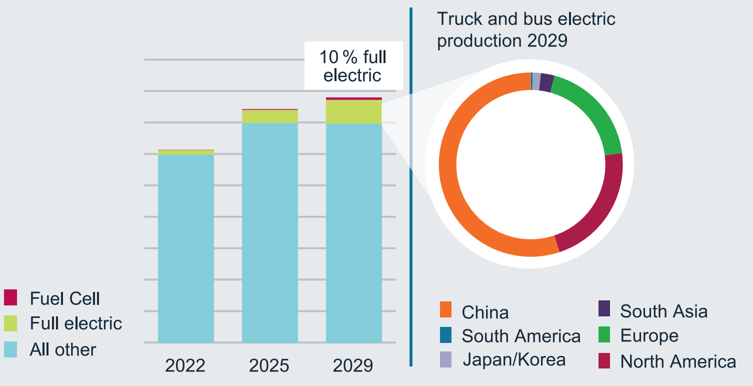
Full battery electric propulsion is one option commercial vehicle Original Equipment Manufacturers (OEMs) are exploring.

In 2021 it was estimated that just over 4% of the combined global bus and truck fleet was fully electric. Looking ahead, as the pressure to decarbonise intensifies, forecasters suggest that by 2029 some 10% of commercial vehicles rolling off the production line will be electric, with the majority produced in China, and small volumes coming from Europe and North America (see visual 1).

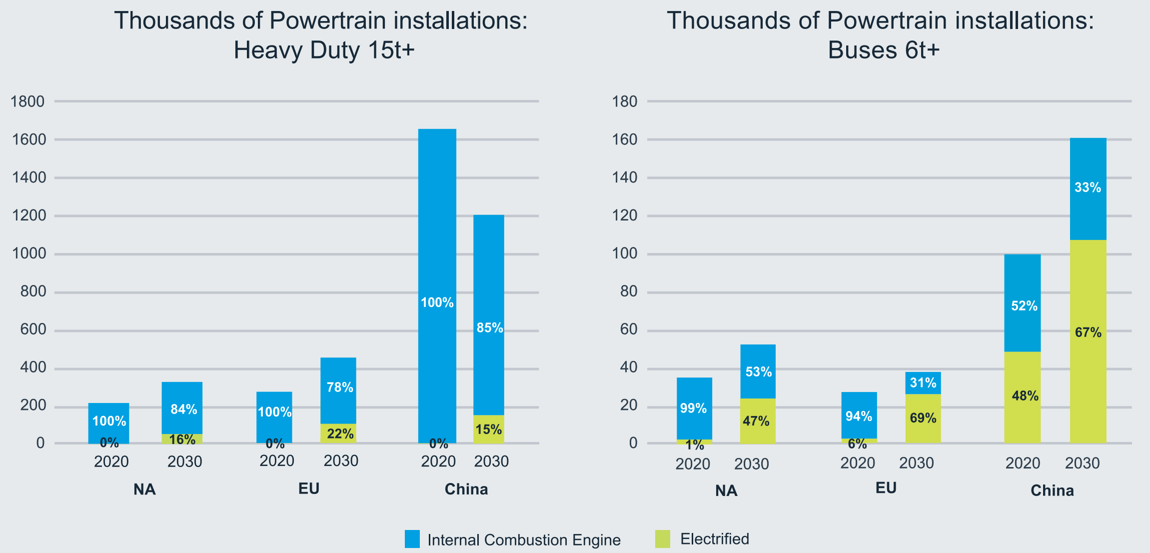
However, more detailed data suggests a faster electrification rate in buses compared to heavy-duty trucks.

Shorter trips and return to base operations where charging can be done overnight, plus local government measures to reduce air pollution in city centres, makes the transition less difficult for buses (see visual 2).

Global production trends of trucks and buses



Source: S&P Global, Global Production based Powertrain Forecast , December 2022



Source: Knibb Gormezano and Partners/GlobalData GCVPTF 3Q23
Note. Hybrid vehicles represent such low volumes they are included in Internal Combustion Engine category. NA data includes NAFTA. EU data also includes the UK and Switzerland

As the hardware evolves, we can expect to see three key drive systems in the market – central drive, integrated eAxle and distributed wheel/ specific hub motors.

Two separate fluids are typically used (one to cool the motor and another to protect the gears), because the position of the motor and gear type means it is challenging currently for one fluid to meet all the requirements of these systems.

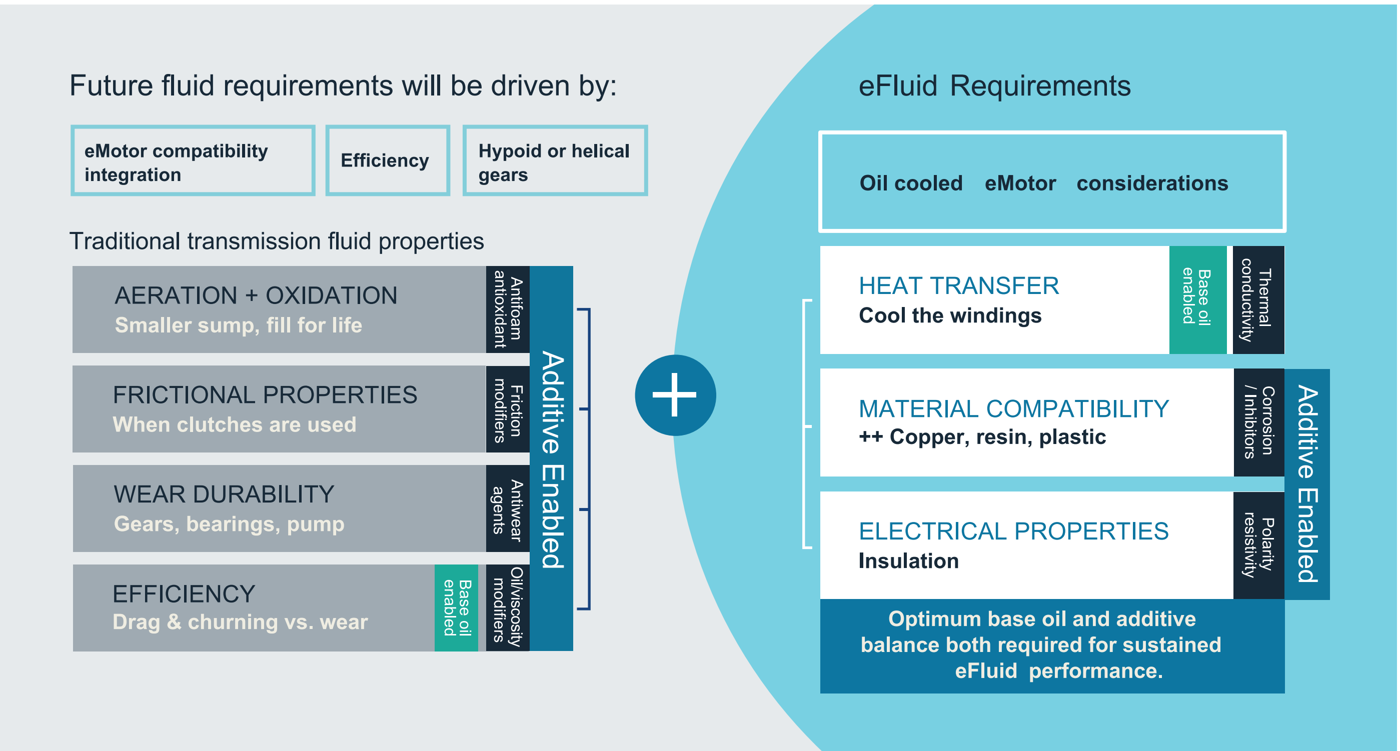
Fluid requirements

In addition, it is challenging to deliver sufficient hardware protection in these fully electric models with the conventional automatic transmission fluids (ATF) and axle oils used today (see visual 3).

Comparing Requirements

✅ Major ⬜ Minor ❌ Not required

	eMotor cooling fluid	eFluid	Axle oil
Motor cooling	✅	✅	❌
Gear protection	❌	✅	✅
Differential protection	❌	✅	✅
Electrical properties	✅	✅	❌
Copper compatibility	✅	✅	❌
Bearing protection	✅	✅	✅
Shear stability	✅	✅	❌
Gear protection	❌	✅	✅✅
Low viscosity	✅	✅	❌



Next generation eFluids will need to deliver not only traditional transmission fluid properties but also new eFluid requirements including improved heat transfer, better materials compatibility, and higher volume resistivit (see visual 4).

Heat transfer for eMotor cooling

Cooling electric motors is recognised as a critical function of electric vehicle transmission fluids. Infineum has carried out extensive assessments to determine the most important properties of eFluids for heat transfer.

While the impact of viscosity and additive technology have been key focal points during tests carried out in different motor configurations, attention has also been directed towards the effect of operating conditions such as flow rate and motor torque.

Heat generation tests revealed that low viscosity fluids offer significant performance benefits versus higher viscosity formulations – delaying derating of stator windings and showing lower steady state temperatures.

However, when moving to lower viscosity lubricants, cooling benefits provided need balancing by an additive technology which also delivers sufficient wear protection.

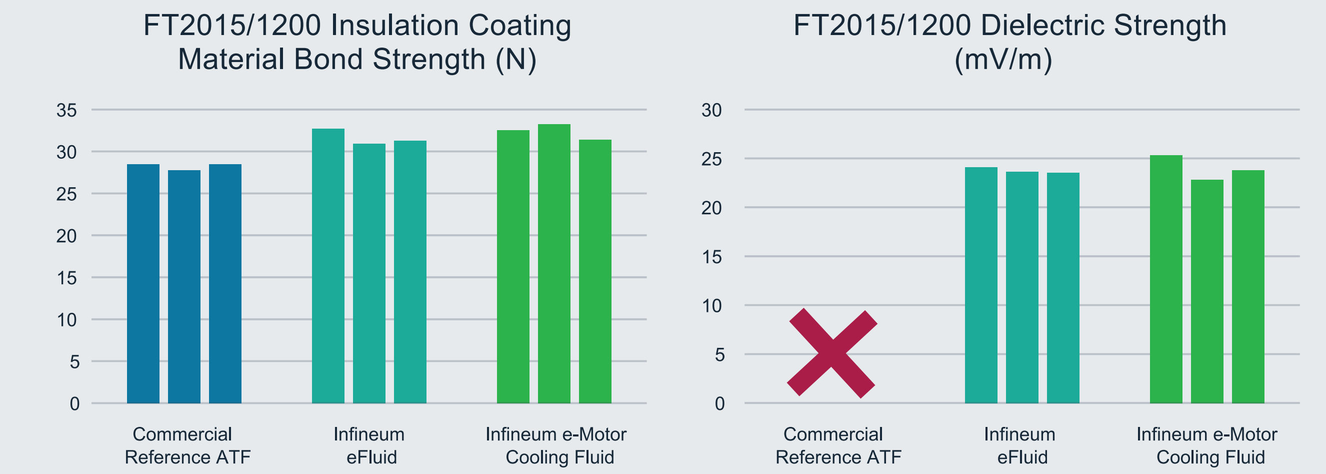
Materials compatibility

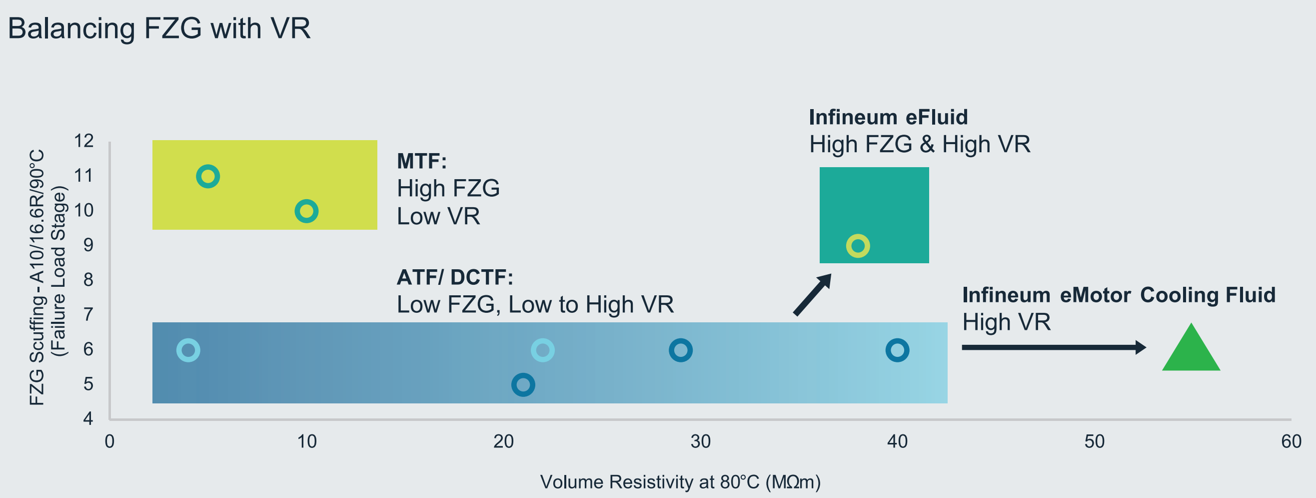
eMotors introduce a wide range of materials into the drivetrain including insulating material, copper wire and connections, aluminium, plastics, and sealants. Many OEMs consider copper compatibility to be one of the most important design parameters for eFluids, because electronic circuit boards are increasingly in contact with or immersed in oil, so full compatibility is required.

The ASTM D130 procedure is one of the most common methods used to study the impact of copper corrosion. But now, newer methods, including energised circuit board tests that involve the passage of an electric current, are also being used to better understand copper corrosion.

In addition, thermal shock testing is a useful way to evaluate compatibility with other materials including varnished wire and a range of insulation materials under extreme thermal cycling conditions (see visual 5).

Using these tests, Infineum's eFluid and eMotor cooling fluid have shown outstanding motor material compatibility performance.





Electrical properties

The issue of electrical compatibility overarches all electric vehicle developments. The power electronics operate at hundreds of volts, which means the fluid needs to provide enough resistivity to avoid any current leakage and/or shortcuts.

However, if the fluid is completely insulating, it can lead to static charge buildup which can damage the equipment due to arcing phenomena. eFluids designed with optimal resistivity can help OEMs to reduce the size of the motor and casing, which means less material use, lower production costs, and enables the use of even higher voltages.

In our view, it is important to tailor eFluid formulations for commercial vehicles to ensure they deliver the right balance of performance to meet individual customer needs.

eFluids need to provide both high gear scuffing and high-volume resistivity performance, making a tailored eFluid a good fit for use in these applications (see visual 6).

Conclusion

A careful balance of additive components and base stock is needed to create tailored eFluids that deliver the required cooling, electrical performance and materials compatibility electric commercial vehicles require. But, at the same time, these complex fluids must also meet gear and bearing durability, aeration and efficiency requirements.

Infineum eFluids have demonstrated improvements in electrical performance, material compatibility and motor cooling efficiency via modelling, novel test methods, eMotor rig testing and field trials in electrified applications. As we look to a future where transmission oils in commercial vehicles will be replaced by advanced eFluids, Infineum is ready with tailored solutions that are aligned with evolving hardware designs.

Visit the Infineum exhibition stand at CTI Berlin to speak to our experts.

JTEKT Ultra Compact Products for Further eAxle Improvement

Makoto NISHIJI, Chief Engineer

Driveline CE Dep't, Automotive Business Unit, JTEKT Corporation

JTEKT contribution for e-Drive system

The automotive industry is developing technologies to respond to the once-in-a-century transformation for realizing a carbon-neutral, recycling-oriented, safe and comfortable society. As the powertrains of automobiles become electrified, the requirements for the e-motor based driveline systems and units that handle the vehicle movement are changing significantly. To take this evolution to an even higher level, reliability and cost reduction are essential, but it is also important to address improvements such as better power consumption (loss reduction, weight reduction, efficient regenerative braking), mountability (size reduction), low NV, and added values (4WD function, Torque control devices, etc.). To achieve this, JTEKT is conducting technological development for e-Drive system by several units/components aiming for "No.1 & Only One" in each field. (Fig. 1)

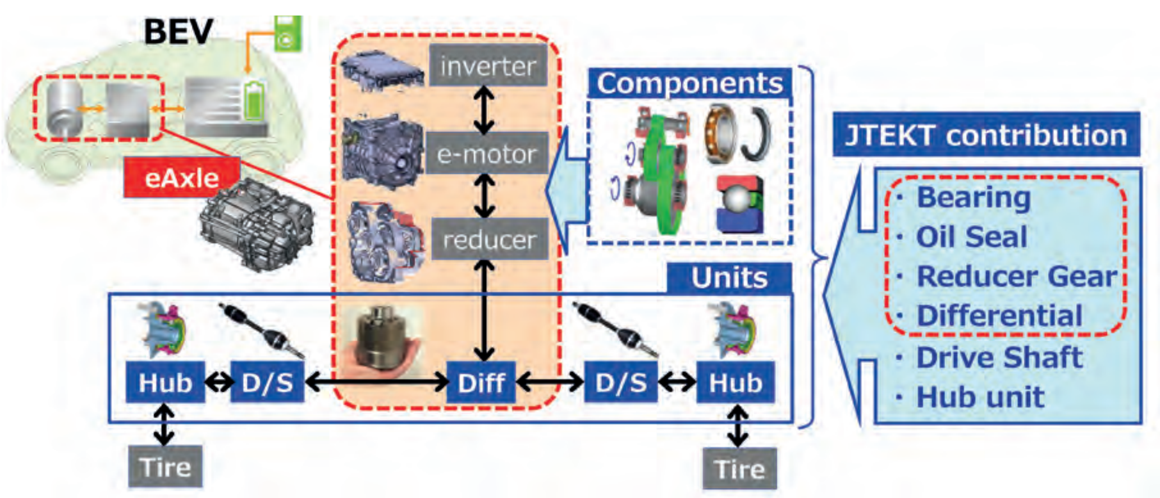


Figure 1: JTEKT contribution for e-Drive system

eAxle improvement by JTEKT Ultra Compact products

Following to the strong demand for higher power density eAxle in future, JTEKT has developed “Ultra Compact” product series, covering Differential (JUCD), Ball Bearing (JUCB) and Conductive Ball Bearing (JUEB), Oil Seal (JUCS) for eAxle size and weight reduction.

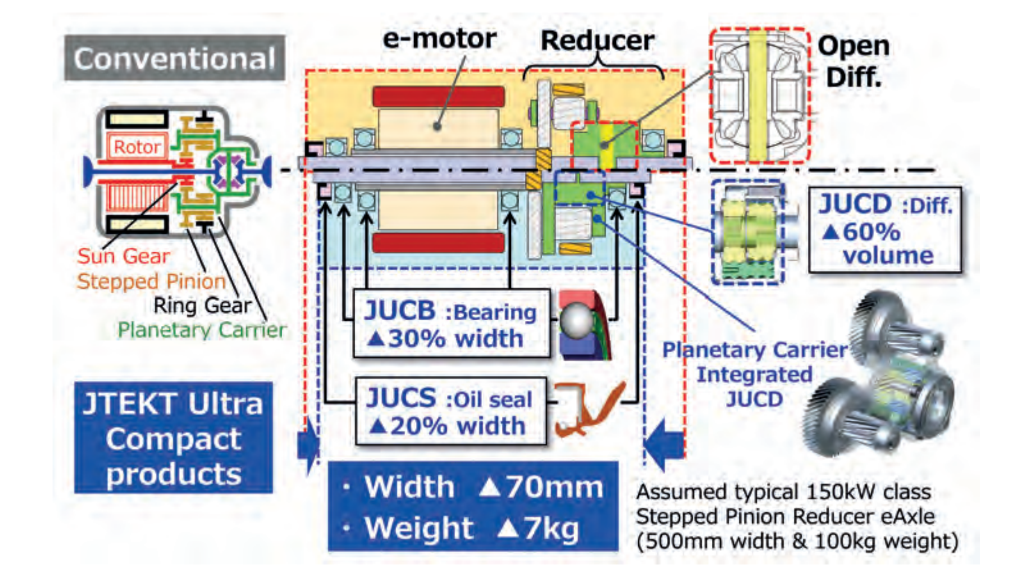


Figure 2: Co-Axial eAxle with JTEKT Ultra Compact products

Fig. 2 shows application example for 150kW class Co-Axial stepped pinion reducer eAxle. Co-Axial eAxle has advantage for packaging in height and front-rear axial length, therefore higher power density compared with traditional 3-Axis parallel offset reducer eAxle, but the eAxle width remains wide because of side-by-side e-motor, reducer, and differential layout. By introducing JTEKT Ultra Compact products, we estimate -70mm width and -7kg weight reduction from typical Co-Axial eAxle arrangement, therefore we can contribute eAxle power density improvement furthermore.

JUCB® Features and Advantages: Compact and High-speed performance

The most important requirement for bearings due to the shift to BEVs is higher rotational speed. In some cases, the maximum rotational speed ratio between the conventional power source, the engine, and the motor can exceed more than three times. The problem is the deformation of the cage due to centrifugal force. With a typical resin cage, when the limit speed is exceeded, the cage pockets deform due to centrifugal force, causing interference with the rolling elements, and the increased rotational resistance causes abnormal heat generation, leading to seizure.

JTEKT has developed a combination cage concept that can minimize deformation. Two resin parts of the same shape are combined to create a structure that suppresses deformation of each other, ensuring cage strength. Furthermore, in order to downsize, JTEKT have developed a bearing, JUCB® (JTEKT Ultra Compact Bearing®), which reduces the bearing width to almost the ball diameter size by minimizing the cage width (Fig. 3).

By optimizing the cage mold and that conditions, JTEKT achieved high-speed rotation of over 2 million dm-n (bearing high-speed performance index: multiplication of ball pitch diameter (dm) and rotational speed) under oil lubrication.

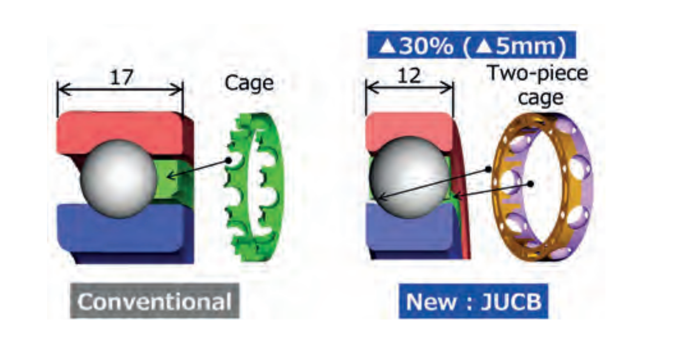


Figure 3: JUCB® (JTEKT Ultra Compact Baring®)

JUEB® Features and Advantages: Compact and Conductivity

In bearings used in motors (especially driven by inverters), a potential difference may act between the inner and outer rings of the bearing due to magnetic flux imbalance inside the motor. Sparks (electrolytic corrosion) are generated at the contact between the rolling elements and the raceway due to this potential difference, which is known to cause washboard-like damage to the raceway. Conventional technology has taken measures to insulate bearings, such as using ceramic balls as insulators and forming an insulating coating on the outer ring surface. In addition, measures have been put into practical use to bypass the potential between the tracks other than the bearings using a separate circuit parallel to the track.

JTEKT has developed JUEB® (JTEKT Ultra Earth Bearing®), which uses a conductive material in the seal to bypass the current path to the seal and avoid electrolytic corrosion on the bearing raceway. JUEB will provide a compact bearing with a conductive mechanism, contributing to improving the reliability of eAxle. (Fig. 4).

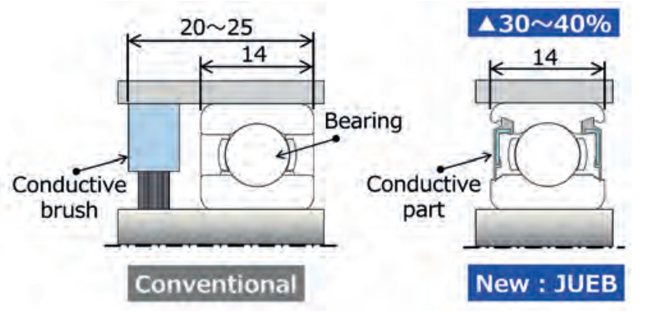


Figure 4: JUEB® (JTEKT Ultra Earth Bearing®)

JUCS® Features and Advantages: Compact and Sealability

The oil seal installed at the connection between the differential and the drive shaft must be able to prevent oil leakage from the inside and contamination from the outside. If the seal width is shortened to make the seal smaller, the lip length will also become shorter, and if the conventional design is used, the ability to follow eccentricity to the shaft will decrease. In addition, the rubber will become hard at low temperatures, worsening the ability to follow the eccentricity. As a result, there was a problem that oil leaks were more likely to occur.

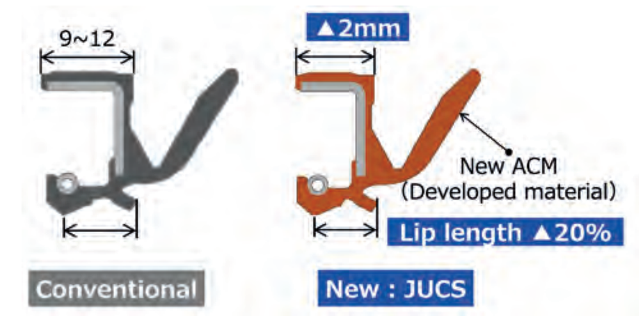


Figure 5: JUCS® (JTEKT Ultra Compact Seal®)

We have developed an acrylic rubber material with improved low-temperature properties and have improved its ability to follow eccentricity at low temperatures by optimizing the tension force composition ratio (rubber, spring). The acrylic rubber also has improved elasticity and can maintain the same oil retention capacity as conventional products. As a result, the JUCS® (JTEKT Ultra Compact Sael®) makes it possible to shorten the seal in the axial direction, contributing to the miniaturization of e-axles. (Fig. 5).

JUCD® Features and Advantages: High torque density and safety performance

Compared to typical bevel gear type open differential, JUCD® (JTEKT Ultra Compact Diff®) has an increased gear mesh quantity and wider gear mesh width at larger gear mesh diameter between planet gear (PG) and side gear (SG). This is possible by using small diameter parallel axis planet gears which are directly supported by the housing bore similar with journal bearing structure. As a result, JUCD has higher torque density (= strength/volume) than typical open diff. Required differential gearing functional volume for JUCD will be less than half compared with open diff. for the same strength. (Fig. 6)

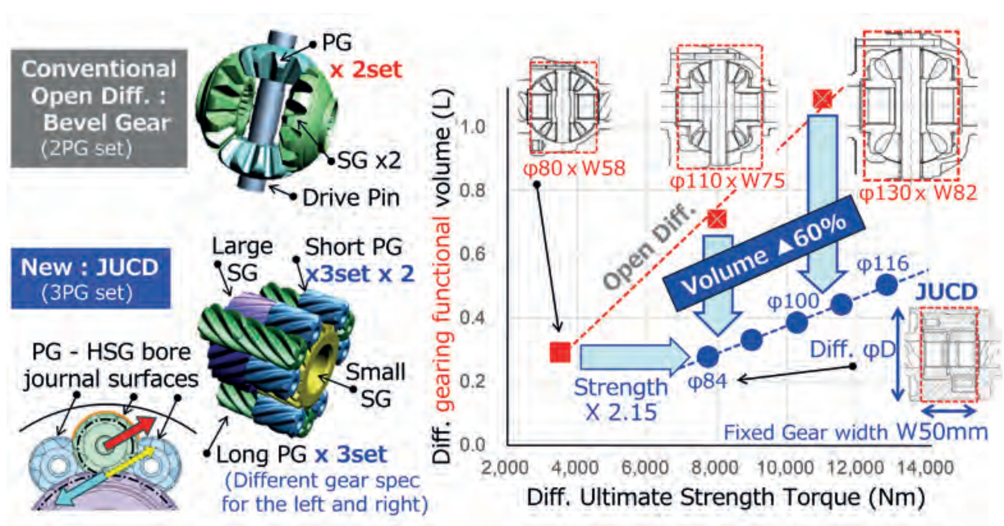


Figure 6: JUCD® (JTEKT Ultra Compact Diff.®)

PG outer diameter – HSG bore direct contact structure generate torque sensing limited slip diff effect, which brings vehicle performance improvement advantages for safe and confident drive under daily various driving situations. This LSD function works not only drive mode, but also coast mode or even regenerating braking mode, therefore it will bring potentially better power consumption for BEV in real world by minimizing wheel slip/spin situation and friction brake activation.

Planetary Carrier integrated JUCD

In case of Co-Axial stepped pinion reducer, planetary carrier and differential housing will have same rotational speed, therefore it is possible to integrate those two functions into one housing, but typical open diff. bevel gear will be located at the side of planetary carrier in to avoid radial dimensional interferences and maintain assembly possibility of the differential components into one-piece housing thru its window. (Fig. 2)

JUCD can reduce differential radial and axial dimension significantly keeping the same required strength. By using this advantage, it is possible to locate the differential well inside of the planetary reduction gearing for reducer width improvement by full axial overlap.

On top of JUCD, JUCB and JUCS could be also integrated into the reducer for further width/weight improvement not only for reducer, but also for eAxle, and even vehicle level. (Fig. 7)

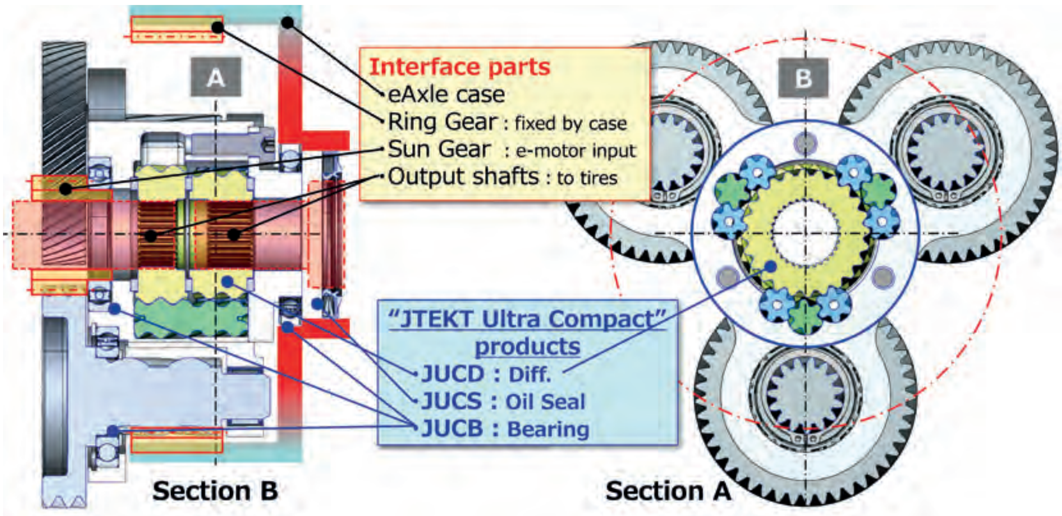


Figure 7: Planetary carrier integrated JUCD in eAxle reducer

Cylindrical JUCD housing together with the same number of differential PG set and reducer stepped pinion gear set reduce planetary carrier stress variation at each stepped pinion support during torque transfer situation. This is also interesting advantage to minimize tooth contact variation of the stepped pinion set, so that it will be easier to define common and optimum tooth micro geometry for the reducer gearing for low NV, and better durability.

https://www.jtekt.co.jp/e/news/

A Game-Changing Solution for OEMs and Tier 1 Suppliers:

Pressure Equalization Element Protects Transmissions During Water Crossings

Source: Konzelmann GmbH

Volker Buchmann, Business Development Manager, Konzelmann

In a world where extreme weather conditions and water-related challenges have become commonplace, the automotive industry faces a pivotal question: How can we equip vehicles for water crossings efficiently while saving time and resources? The answer lies in a groundbreaking innovation that is poised to revolutionize how we approach water crossings and offers OEMs and Tier 1 suppliers a transformative advantage.

Safeguarding against the elements

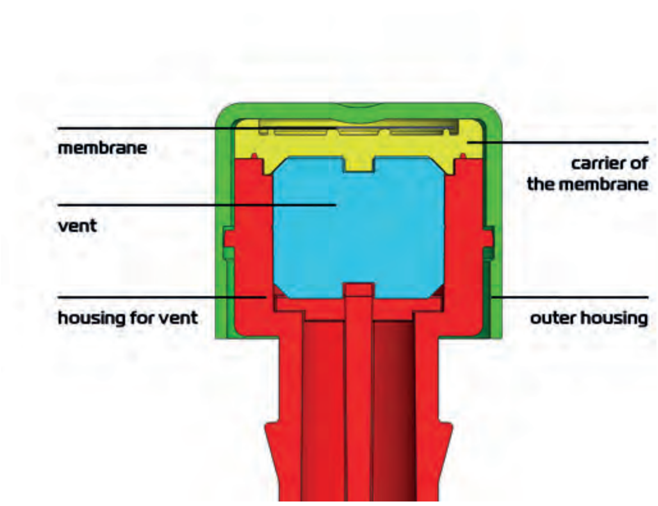
Throughout this past summer, extreme weather conditions occurred all over the world, with extraordinarily strong rainfalls accompanied by heavy thunderstorms and an increased risk of flash floods. When tunnels or underpasses are flooded due to continuous rain, there are often only two options: detour or wade through. Vehicle drivers tend to overestimate their vehicle's ability to cross water. In these situations, water or mud can quickly infiltrate the transmission resulting in a failure that only a towing service and costly repairs can resolve.

While vehicles usually are equipped with a hose construction to manage water crossings, there was no simple technical solution for wading through water. Until now. The newly designed Pressure Equalization Element (PEE), directly integrated into the transmission, prevents both positive as well as negative pressure within closed housings in electric axes and differentials, promising new perspectives for reducing product costs and time to market.

Hose construction: elaborate and costly

As mentioned, to prevent water from entering, a hose is connected directly to the transmission, providing ventilation during pressure variations. Although the hose construction is suitable for water crossings and is installed as standard, it is considered elaborate in design, resulting in time and cost-intensive assembly. Currently, there is a lack of a simple technical solution for water crossings.

The solution to this challenge is the Pressure Equalization Element (PEE), a pioneering innovation designed to fit directly into the transmission housing. The PEE houses an internal pressure-regulating valve that swiftly balances pressure differentials, safeguarding the ventilation space against contamination and the intrusion of liquids. Operating at 70 mbar, equaling a water column of 70 cm, the valve withstands exposure to gearbox oil aerosols, typical vehicle substances, and environmental materials.



Konzelmann's Pressure Equalization Element protects the system seals from damage due to positive or negative pressure. Source: Konzelmann GmbH

A membrane that defies liquids and contaminants

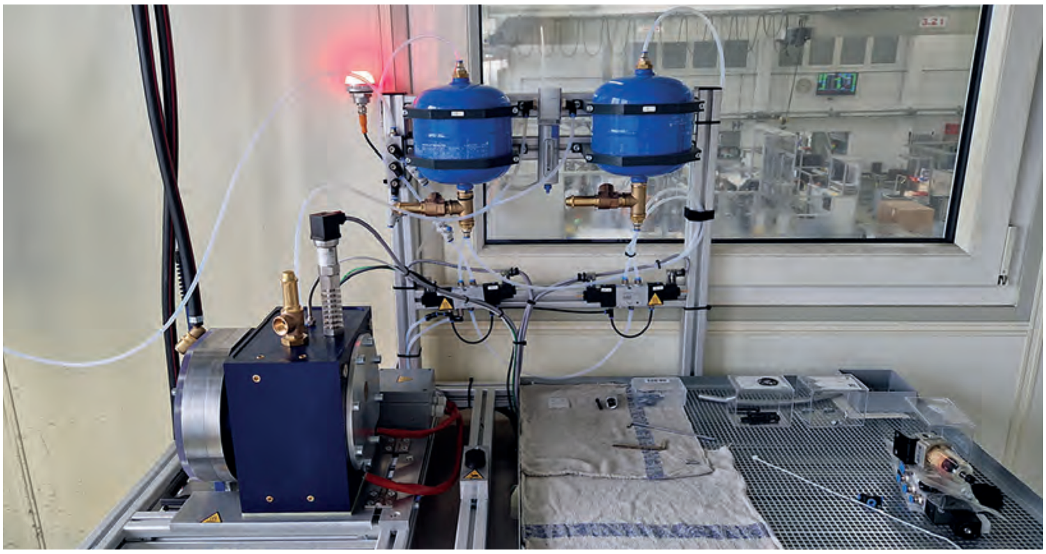
In contrast to a conventional hose system, the PEE is securely integrated within the electric axle housing. The pressure equalization valve, designed to prevent positive pressure, allows escaping gas to exit through a lateral opening in the housing while permitting air to flow in during a negative pressure situation in the housing. This air passes through an air-permeable yet waterproof Ventikon membrane. This membrane is capable of withstanding a water column of 30 meters, effectively blocking liquids as well as contaminants, safeguarding the electric axle against foreign objects.

At a defined negative pressure, the valve opens, enabling air to flow in to equalize the pressure difference. The PEE's membrane is thoughtfully shielded, preventing it from being coated with spray oil. Furthermore, a labyrinth-like oil separator, positioned between the valve and the electric axle's interior, shields the valve from direct contact with splashing oil.

Simulating real-world performance

Konzelmann, in collaboration with an OEM and a Tier 1 supplier deeply involved in transmission and differential development, has conducted in-depth analysis and established testing parameters for a dedicated testing environment. This in-house testing platform enables accurate simulation of transmission behaviour, allowing precise customization of the pressure equalization valve to meet the unique requirements of each manufacturer.

The testing setup mirrors the oil and air volumes within a transmission housing, ensuring a comprehensive evaluation of the system's performance throughout its lifespan. Information from the transmission manufacturer regarding residual air content in the transmission guides the testing process. The artificial transmission is then filled with the manufacturer's original transmission oil and subjected to controlled heating, creating positive pressure and pressure equalization. When the oil and air cool, a vacuum or negative pressure forms, drawing in outside air through the membrane. This testing approach has already successfully simulated 8,000 kilometers of test drives.



The Konzelmann endurance test stand for load spectra of oil temperatures of up to 120 °Celsius

A consultative approach

Thus, for the first time, a valve has been developed that optimally functions during the critical phase of water crossings, ensuring that the membrane remains unclogged with oil. All gearboxes available on the market can be tested in advance and manufacturers can be advised optimally.

This groundbreaking product innovation is adaptable to all vehicle types and drivetrains, even within mobile systems. It is characterized by its minimal installation requirements and space-efficient design. The precisely defined ventilation and exhaust mechanism guarantees optimal pressure management within transmissions and other systems. Additionally, the Pressure Equalization Element offers a distinct production advantage over conventional hose constructions: It enables vehicle rotation on the production line even after the transmission/e-axle unit has been filled with oil.

Currently, the product is already undergoing testing with an OEM, with production scheduled for 2024.

About Konzelmann

Konzelmann GmbH, headquartered in Löchgau between Stuttgart and Heilbronn in south-western Germany, develops and produces high-quality plastic injection molding products. For more than 60 years now, Konzelmann has planned, developed, and manufactured high-precision components and complex assemblies made of polymeric materials for the medical, automotive and industrial sectors. Their extensive experience has made them a market leader in the fields of highly specialized technical applications. Furthermore, Konzelmann has a global presence, with representatives in Detroit/USA, Seoul/Korea and New Delhi/India.

More information: https://www.konzelmann.com/en/expertise

Overcoming Challenges to High-Speed Electric Motors

Craig Renneker, Vice President Innovation, AAM

While the EV growth rate remains uncertain, there is little doubt that the use of automotive electric drive units must drastically increase to meet global climate objectives. This requires mass market acceptance across the full range of vehicles – size and price. A major enabler to reaching more customers is to reduce the cost, size and mass of Electric Drive Units (EDUs), as well as the quantity of natural resources required in manufacturing.

The power produced by an EDU is a product of its torque and rotational speed. Increasing the rotational speed enables power to be achieved at a lower torque. Simply put, spinning the motor faster reduces its size, mass and cost (Figure 1). The result: fewer costly materials are required, such as copper windings, magnetic steel and, in some cases, rare-earth magnets.

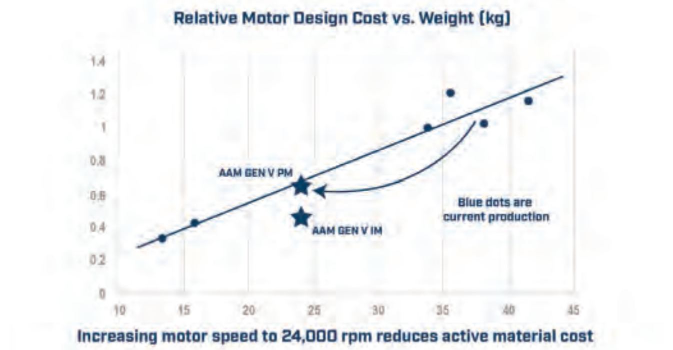


Figure 1 Electric Motor Cost vs Mass

Traditional electric motors rarely spin to 20,000 rpm. Exceeding this level requires careful motor, gearbox and inverter design. This article discusses the approach AAM is taking to overcome various design obstacles to enable speeds up to 30,000 rpm – the speed needed to make a real impact in clean mobility and customer acceptance of EVs.

The Integrated Approach

An accessible EDU with a 30,000 rpm motor requires an integrated motor, gearbox and inverter. Each area presents specific challenges to execution and opportunities for new designs:

- Motor: pole count, rotor centrifugal forces, cooling, sealing and bearings
- Gearbox: pitch line velocity of the gear teeth
- Inverter: Switching losses

The Motor

Most electric motors employ stators with 3-phase copper windings driven by sinusoidal alternating current. As the frequency of these sinusoidal currents increase, parasitic power losses in both the magnetic steel laminations and copper conductors increases. These are commonly called iron and copper AC losses. The required frequency for a 3-phase motor is determined by the motor pole count and rotational speed. Most motors today are 8-pole designs with interior permanent magnets. AAM uses a 4-pole architecture which requires half the sinusoidal current frequency of an 8-pole design. This significantly reduces iron and copper AC losses. (Figure 2)

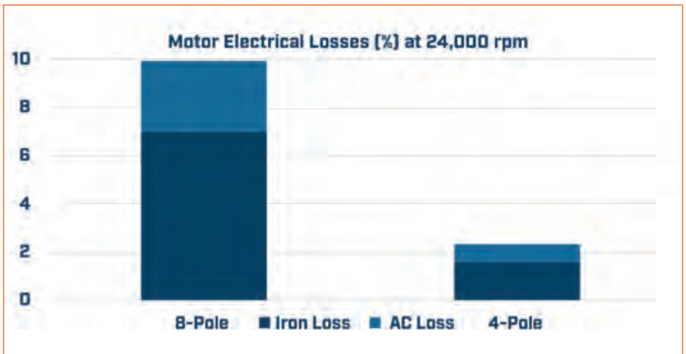


Figure 2 Iron and Copper AC Losses

Reducing the diameter of the rotor enables higher speeds. Fortunately, higher-speed motors require less torque for a given power level, allowing a smaller diameter. As an example, the tangential speed of an 87 mm OD rotor at 24,000 rpm is lower than a much larger rotor spinning at 15,000 rpm (Figure 3). Using stress analysis of the lamination and magnet geometry, high speeds can be attained.

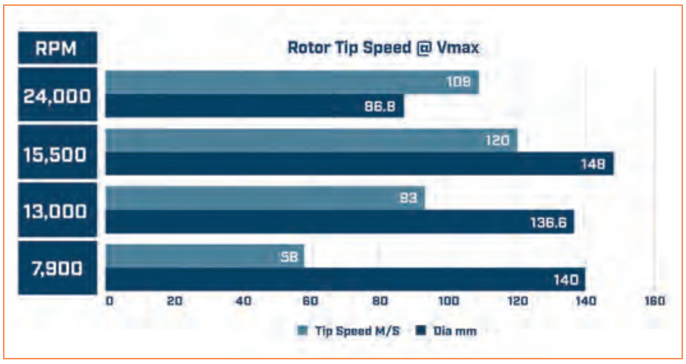


Figure 3 Rotor RPM and Tangential Speed

Smaller, fast turning motors have basic geometric challenges in removing heat. To effectively remove this heat AAM uses forced oil cooling of both the stator and rotor. A series of stamped holes in the stator laminations are arranged to form helical cooling passages around the copper windings. Oil is also pumped into the hollow rotor shaft with special heat sink features to increase surface cooling. This method reduces the heat generated in both the stator and rotor without the need for a glycol-cooled motor jacket.

AAM is employing a completely different approach to cooling high-speed rotors. Instead of pumping glycol coolant through the hollow center of the rotor requiring radial lip seals, AAM is cooling the stator, rotor and inverter with the same low-viscosity oil used to lubricate the gears and bearings. With this arrangement, no sealing is required between the rotor and gearbox elements.

In most EDUs, a simple 2-stage helical-gear reduction is used to step motor speed down to the vehicle wheel speed. The pressure angle of the gear teeth generates a radial load proportional to gear torque that must be carried by bearings on the rotor axis. With a typical single-mesh, 2-stage helical gear reduction, bearing capability limits motor speeds to 20,000 rpm. AAM uses a dual-layshaft gearbox arrangement to balance these gear separation loads, which enables traditional small bearings to be used. (Figure 4).

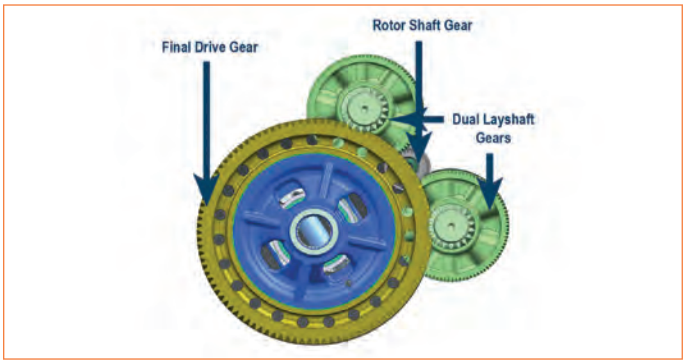


Figure 4 AAM Dual Layshaft Gearbox Layout

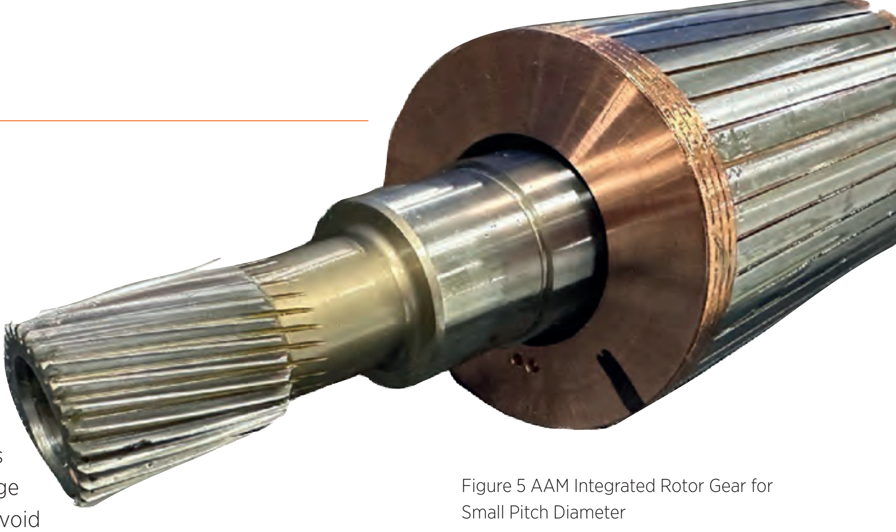


Figure 5 AAM Integrated Rotor Gear for Small Pitch Diameter

Gearbox

Higher motor speeds require higher gear ratios to maintain normal wheel speeds. Any ratio can be accommodated with enough successive reduction stages. However, each additional stage adds cost, mass, package space and parasitic loss to the gearbox. Typical low-speed drive units employ a 2-stage reduction. As such, it is desirable for a high-speed motor to avoid the penalty of adding a third reduction stage. The critical enabler for high ratio (up to 22:1) is keeping the first stage drive gear very small. By keeping the motor off the wheel axis AAM enables the rotor shaft drive gear pitch diameter to be very small to provide a large reduction in the first stage and reduce pitch line velocity (Figure 5).

Inverter

The inverter converts DC battery voltage into multi-phase AC that drives the stator of the electric motor. The frequency of the required sinusoidal current is directly proportional to the motor's rotational speed and its number of magnetic poles. The inverter induces this sinusoidal AC to flow in the stator windings using pulse-width modulation (PWM) of the battery voltage (Figure 6). Pulse-width modulation involves solid-state switching devices that can turn on and off very quickly. Each on/off cycle results in a small amount of energy being lost within the switching device. As such, higher sinusoidal frequencies require faster switching, which increases inverter losses.

AAM's 4-pole motor design operates at half the sinusoidal frequency of a traditional 8-pole motor. This enables the motor to spin at twice the speed with equivalent inverter switching losses.

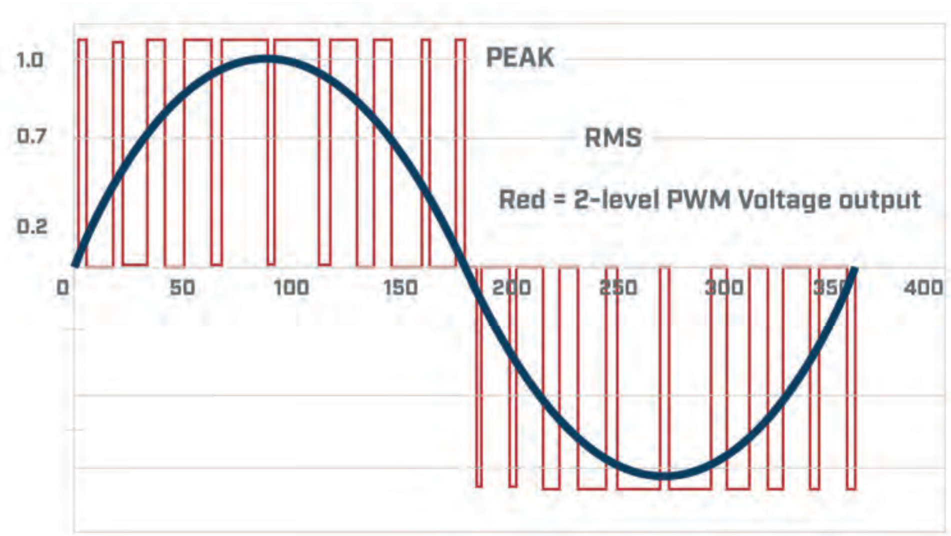


Figure 6 Motor Sinusoidal Phase Current and PWM Signal

Conclusion

AAM continues to push the limits of electric motor speed in EDUs. The company has several demonstration vehicles and one pre-production application running at 24,000 rpm, with an additional development unit producing 30,000 rpm. These designs can be produced at low cost in high volume using practical engineering solutions overcoming previously perceived limiting factors. These designs can enable the growth of EDUs into a wide variety of vehicle applications, thus creating a broader impact on carbon reduction and clean transportation. Innovations at AAM are creating efficiencies for our customers, satisfaction for consumers and an increased opportunity to positively impact our environment.

JJE 2-Speed Electric Beam Axle for Medium Duty Truck

Ping Yu, CEO, Chief Engineer, Founder, Jing-Jin Electric

Dr. Yang Cao, Transmission Senior Supervisor, Jing-Jin Electric

The electrification of medium duty truck grows rapidly. JJE's newest electric beam axle family can cover up to 11T (or class 6 in North America) trucks, including single-speed and 2-speed systems. Multiple advanced technologies are integrated into the electric beam system, such as bi-stable electromagnetic bi-directional shifting clutch, bi-stable eLocker, linear park lock system, and active cooling and lubrication. These functions' control is all in the electric beam axle's inverter, which is mounted on the axle. 800V, high power hairpin motor and SiC inverter are used to produce strong capacity, and high efficiency across wide operating range.

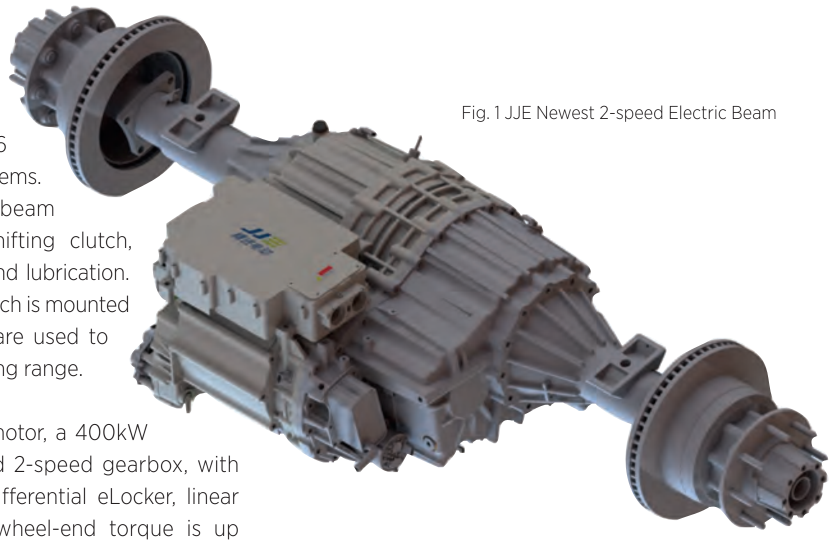
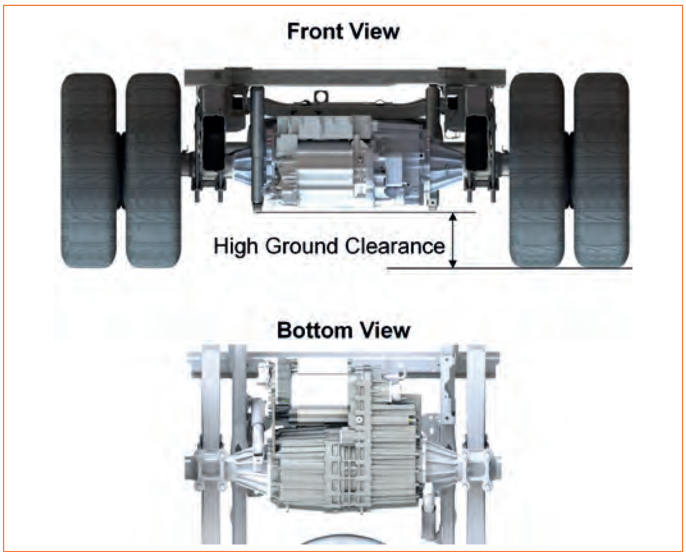


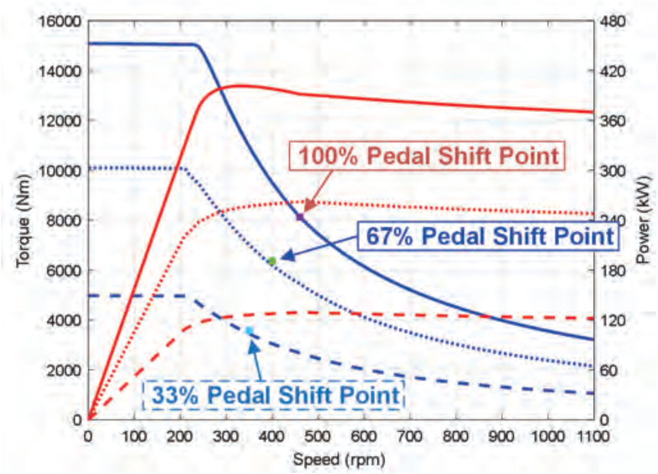
Fig. 1 JJE Newest 2-speed Electric Beam

The 2-speed axle features a high efficiency hair-pin electric motor, a 400kW SiC inverter with "safe towing" feature, electro-magnetic shifted 2-speed gearbox, with neutral position that also serves as a disconnect, bi-stable differential eLocker, linear park lock system. With 2-speed gearbox, the beam axle's wheel-end torque is up to 15,000Nm, and the maximum vehicle speed is over 160km/h. Integrated design for motor and gearbox reduces the axial length of the system.

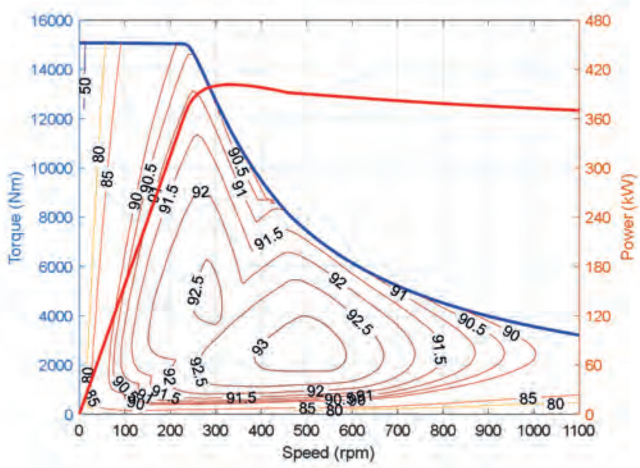


JJE's 2-speed beam axle features high performance and high output speed, with little power degradation at high speed. Its efficiency is high over a wide speed range – especially in comparison to a single speed axle thanks to the 2-speed gearbox.

Fig. 2 JJE Electric Beam at the Rear of a Truck Demonstrator



a. 2-speed Electric Beam Shifting Feature



b. 2-speed Electric Beam Efficiency

Fig. 3 JJE 2-speed Electric Beam Performance

Electric Motor

JJE has a mature hairpin motor designs to cover performance requirement of wide range of vehicles. For this electric beam axle system, the electric motor's peak power reaches 420kW at 650Vdc, with 97.4% maximum efficiency, and over 90% of the efficiency map is above 88%. The water-oil combined cooling allows the electric motor to produce high continuous power.

2-speed Gearbox

The 2-speed gearbox provides high launch torque, high vehicle speed and high efficiency over broad duty conditions, and helps contain motor's top speed for better reliability and durability. It also broadens high efficiency operating range, and significantly reduces thermal loading in the system at high speed. A 2-way, bi-stable electromagnetic clutch is used for shifting between 1st gear and 2nd gear, with neutral position. The neutral position is a natural "disconnect". Combining this rear axle with neutral with a constantly powered front eAxle, the vehicle efficiency can be improved. JJE's patented **DirectFlux^{TM}** Bi-stable eLocker enhances functional safety of the locker and eliminate the power consumption. Proven park lock system is implemented on the motor shaft, or the "lowest torque" point of the system. An oil pump provides active oil lubrication, which allows low oil level in the gearbox, reduces gear churning loss.

SiC Inverter

The electric beam axle has an 850V SiC inverter integrated on it, with functional safety level up to ASIL D. Multiple functions – such as motor control, differential locker control, 2-speed transmission control, park lock control – are integrated in the inverter, taking advantage of inverter's high functional safety control platform. With backup power supply, the inverter enables "safe towing", a feature highly desired by customers. It is a critical safety redundancy in the event of 12V power supply loss.

DirectFlux^{TM} Bi-stable Electromagnetic Clutch

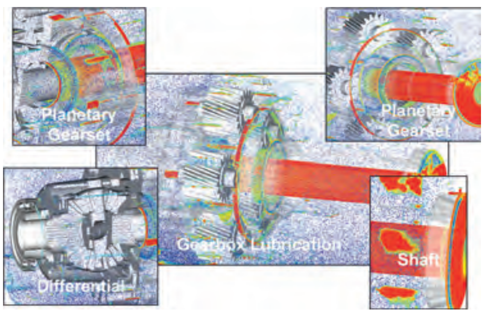


Fig. 4 Active Lubrication System

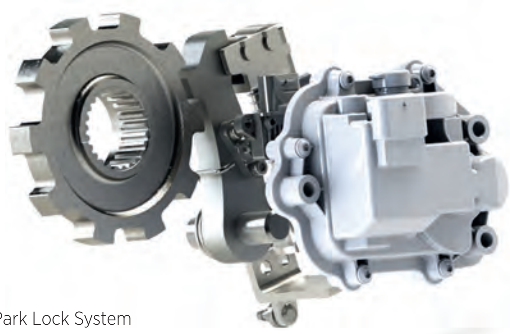


Fig. 5 Linear Park Lock System

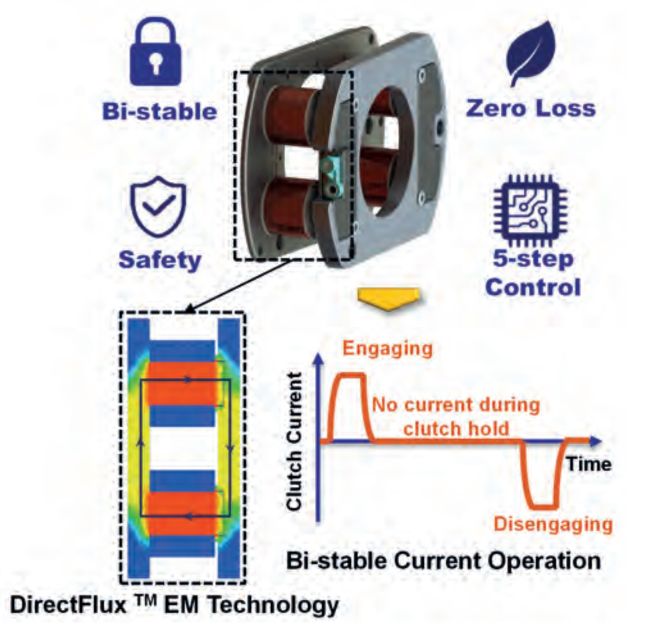


Fig.6 JJE DirectFlux^{TM} Bi-Stable Electromagnetic Clutch

Patented bi-stable electromagnetic clutch is JJE's one of the most advanced technologies. It is used for gears shifting and locking the differential in the electric beam axle system. This technology has been successfully used as a differential locker in JJE's 300kW SiC EDM and as a disconnect in JJE's new AWD EDM.

DirectFlux™ electromagnetic clutch takes advantages of its innovative magnetic circuit design. Compared to the more conventional reluctance flux magnetic circuit design, the **DirectFlux™** design greatly reduces flux leakage, and therefore utilizes magnetic flux more effectively to generate force. However, the conventional reluctance flux design cannot avoid magnetization of parts near flux circuit, or "flux leakage", which causes less effective utilization of magnetic flux. As a result, DirectFlux acts 2-3 times faster than a reluctance flux design.

The bi-stable clutch is inherently fail-safe as it won't change state in the event of loss of power. This feature gives bi-stable clutch a higher safety level than mono-stable clutch. For differential locker, it will prevent sudden locker release due to the loss of power or control failure. For transmission shift, it will prevent gear unexpected back to neutral which will lead the vehicle loss of traction. On energy consumption side, the bi-stable clutch's feature of "zero holding current" eliminates holding current and in turn achieves zero power consumption.

In the development stage of an electromagnetic clutch, a software platform based on several simulation tools is built for more precise simulation result. This platform covers signal, electric, electromagnetic, and mechanical aspects. It addresses almost every detail, including software control, PCB layout, electromagnetic transient simulations, multi-body dynamic simulations, and strength. It provides strong support to the clutch's development.

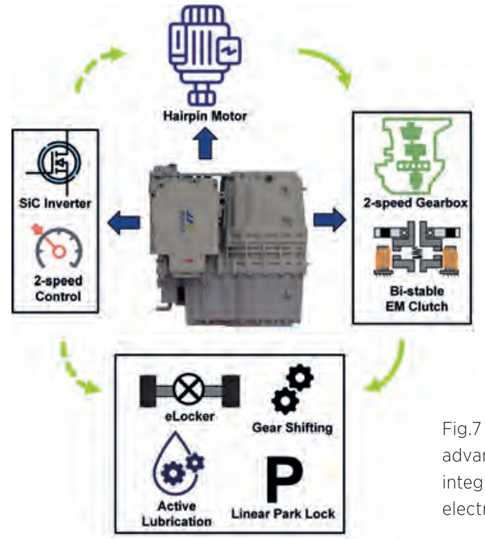


Fig.7 Multiple advance technologies integrated in the electric beam system

Electric beam axles are designed for pickup trucks, light duty trucks, or medium trucks. As the beam axles get electrified, a lot of traditional technologies no longer fit. JJE takes advantage of its knowledge in electric drive, strong R&D capabilities on motor, inverter, transmission and clutches and expertise in system integration, creating the 2-speed electric beam axle for the large medium truck segment.

eS4500i: Highly Integrated Electric Drive Unit for Multiple Applications

Marco Silvestri, Chief Engineer, Dana Incorporated

Across all our actions, we never lose sight of a guiding vision toward a zero-emissions future. This has powered our first-mover advantage in electrification.

At Dana, we strategically invest in technical competence – designing, engineering, and manufacturing the components of a complete e-Propulsion system in-house. These innovations include efficient EV systems and new electrodynamic products like motors, inverters, controls and software, battery cooling systems, and metallic bipolar plates for fuel cell applications.

The legislation for pollutants and emissions is driving OEMs to design their reduction programs to align with aggressive timelines — accelerating the adoption of electrification. These mandates, coupled with corporate commitments from OEMs, will significantly increase the demand for electrified vehicle architectures, the main components of a Battery Electric Vehicle.

Dana's solution is the Spicer® Electrified eS4500i e-Drive Unit – a highly versatile 3-in-1 electric drive unit (EDU) that converts the stored electrical energy from the battery into mechanical power to the wheels.

Fig. 1: eS4500i main components: inverter, motor, geartrain, differential, park-lock

eS4500i Platform

Utilizing competencies from Dana's global network of technology centers, the highly integrated eS4500i comprises an inverter, motor, one-speed geartrain, open differential, and optional park-lock.

The thinking behind the eS4500i was really to provide more than a single EDU. What was needed was a versatile platform offering multiple ratios and integrated design of motor and gearbox while also taking into consideration efficiency, optimized packaging space, and lower weight.

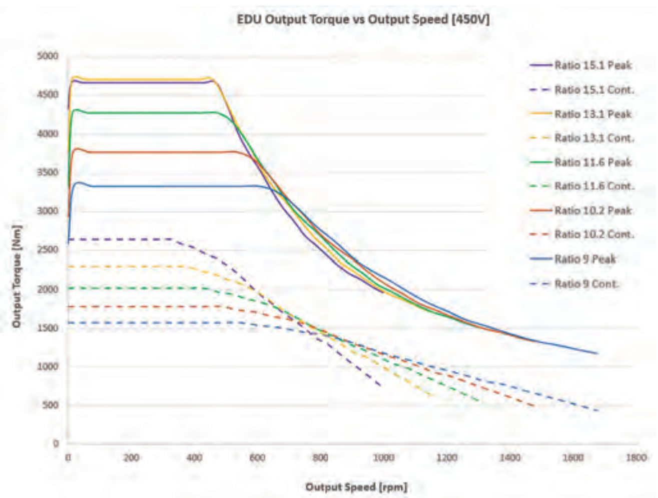


Fig. 2: System output torque vs. output speed [450V]

To cover multiple applications, five different ratios were designed (macrogeometry) with the same center distances, same gear width, and similar envelopes diameters also recombining the same gears to reach five different ratios.

In this way, with a unique design of the housing and bearings, the eS4500i can host five different gear-trains to be able to match different vehicle requirements in terms of maximum torque and speed.

From figure 2, it's appreciable the spread of torque and speed that the system can cover with the five different ratios options.

A limitation of around 4,500 Nm (as max nominal output torque value) has been decided for ratio 15.1 and 13.1 because of match with other Dana products but useful in case of demanding vehicle gradeability and high continuous torque.

Highly Integrated Layout

The design of the gearbox and the motor was improved by integrating the components as much as possible to provide a light, compact, and power-dense EDU.

For the eS4500i, it has been decided to have a highly integrated design between the motor and gearbox to save weight and to improve the power density.

Only three housings compose the structure of the EDU and shape two separate environments: a dry one for the motor and a wet one for the oil-lubricated gearbox.

Referring to figure 3, from right to left:

The motor back-case supports the rear motor bearing and becomes the seat for the stator and the internal side of the motor cooling jacket. The helical cooling path is made by die-cast molding for manufacturing efficiency.

A carrier housing supports the front motor bearing and becomes one of two gearbox housings as well as the external side of the motor cooling jacket to complete the sealed channel.

The cover housing enclosures the gearbox components.

One of the main characteristics of the highly integrated layout is the over-hanged pinion gear directly mounted on the head of the rotor shaft. Between the pinion gear and the motor front bearing, there is a parking gear.

The layout is completed by an intermediate shaft and an open differential, both supported by taper roller bearings.

This new layout reduces the interfaces between the gearbox and the motor to achieve a precise axial centering of the gearbox with the output shaft of the motor. This also allowed a significant reduction of components like having only two bearings on the input axis, a reduction of the number of housings and a significant a reduction of fasteners.

The EDU is completed by the inverter that is direct-mounted on top of the motor with the high voltage connections passing through the back housing.

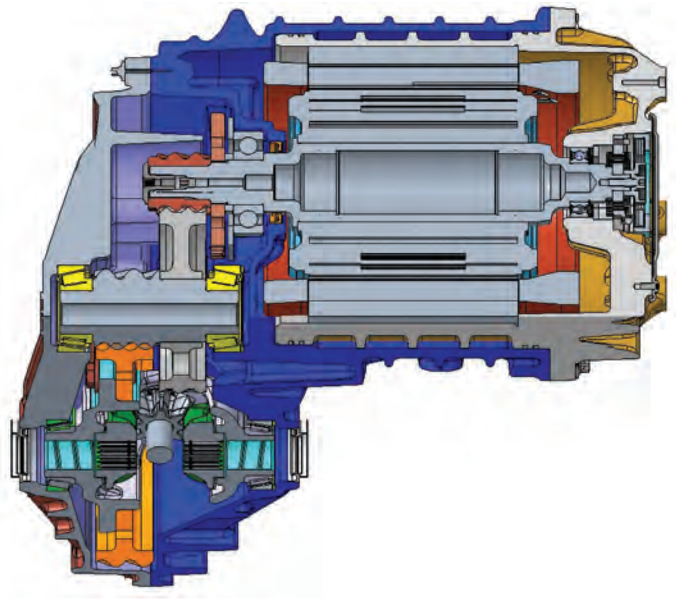


Fig. 3: Section overview – motor-gearbox highly integrated design

The park-lock adds another degree of flexibility because it can be added or removed on customer request. This park-lock option is already patented and in series production, with a mechanism layout now upgraded with a new smart actuator.

Motor and Inverter

The eS4500i is powered by a propulsion system composed of an asynchronous dry 450V motor and with a Dana 2nd generation direct-mounted inverter.

Performance Resume		
Motor Peak Power @450V	238	kW
Motor continuous Power @450V	128	kW
Motor Peak Power @350V	188	kW
Motor continuous Power @350V	110	kW
Motor Peak Power @300V	162	kW
Motor continous Power @300V	99	kW
Max motor torque	380	Nm
Max motor speed	15,000	RPM
Motor overspeed for 2 minutes	18,000	RPM

Tab. 1: eS4500i motor data

The propulsion system is cooled by water-glycol and the theoretical performance curves are shown in fig. 5 at 65°C coolant temperature.

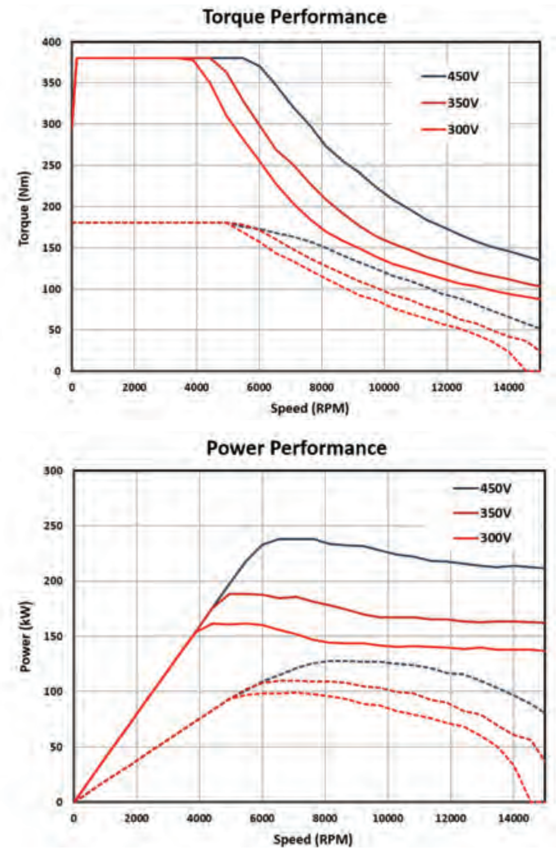


Fig. 5: eS4500i motor curves

Since this propulsion system is for a medium voltage (450V) application, Dana decided to use the latest IGBT module technology for this inverter over the newer SiC MOSFET technology. This allows the use of our proprietary Reflex gate driver technology to achieve the most cost-effective solution for this voltage range.

Conclusion

As a Tier 1 supplier, Dana offers its new eS4500i EDU, an off-the-shelf solution on the path to electrification, with a compact and light package for a wide range of applications.

The eS4500i is equipped with the well-known Dana differential from a robust off-road heritage, with an optional park lock system.

Dana is offering its all-new configurable off-the-shelf eS4500i EDU to a multitude of segments and applications. This work is the result from the synergy between the different technical centers and other global Dana branches, putting together different competencies. With its power density, reliability, and cost competitiveness, this product will contribute to our customers' success on the path to electrification.

Interview

"Hybrid Solid State Batteries can be More than an Intermediate Step"

Dr Thomas Christian Hülshorst is Group Vice President Electric Powertrain at FEV Group.

At the CTI Symposium USA in May 2023, Dr Thomas Hülshorst, FEV, discussed battery requirements for different levels of vehicle electrification. We took the opportunity to interview him about the various requirements of low-voltage, HEV and BEV applications, battery safety – and hybrid solid state batteries that could soon offer greater safety and energy density.

Dr Hülshorst, you predict that Li-Ion batteries will even replace low-voltage batteries in future. Why is that?

We are already seeing more differentiation than with classic 12V batteries. Vehicles with highly automated driving functions require a fail-safe on-board power supply, to name just one example. Low-voltage batteries must meet these requirements and provide superior reliability and functional redundancy. In addition, lithium-ion-based batteries come with a reduction of weight and volume and a much longer lifetime than lead acid batteries. And then there's the lead ban, which is discussed in the EU. So that's why we are confident that lithium-ion technology will have a significant share in low-voltage batteries in the longer term.

You also see specific requirements for hybrid drives. They have far more charge cycles than those in BEVs, for example; what does that mean in terms of their configuration?

Yes, you are right. Load cycles in a hybrid application are completely different, with a much higher number of cycles at a much lower depth of discharge. In addition, the batteries in hybrid drives have much less capacity than in pure electric cars, but still need high power. The battery cells must therefore have a much higher C-rate, which means that the charge and discharge currents are high in relation to the relatively low energy content. These requirements call for a completely different cell design.

To increase the electric range, the energy density of BEV batteries needs to be increased. What opportunities do you see for improvement here?

There are several interacting factors here. It is important to consider that for a given vehicle efficiency, a BEV's electric range is a function of its battery's energy content. Since the packaging space available for the battery is limited, obviously the battery cells need high volumetric energy density. However, the cell integration into the battery pack and the vehicle is just as important. Are they cylindrical cells, are they prismatic cells? How are they integrated? How to design battery packs, which are safe and offer high capacity at the same time? The answer lies always in the combination of battery cell and the pack design. With a cell-to-pack design using large prismatic battery cells, that are optimized for vehicle integration, very good energy densities can be achieved, even using lithium iron phosphate cells with less cell-specific energy density but high thermal stability and safety. However, solid-state batteries are now almost within reach, too – the so called 'hybrid solid state' battery technology already today offers a wide range of solid-state related advantages with a relatively good maturity level. In terms of energy content, these cells won't yet achieve the full potential of a lithium-metal anode, but they already reach almost 1,000 Wh/l at cell level. So basically, it's all about the interaction between cell technology, cell design, and package design.

What does 'hybrid solid state' battery technology mean?

You might consider this technology as an approach to bring together the best of two worlds. Solid-state battery cells offer high mechanical stability. This enables the use of high energy density anode materials like SiOx, Si or even Li-Metal. However, a disadvantage of solid-state electrolytes lies in the high ionic contact resistances between cathode, separator, and anode. But this can be well balanced by adding a liquid electrolyte with a very good ionic conductivity. In addition, the liquid electrolyte costs less, and is lightweight; the solid substrate offers a high level of safety. By combining a solid substrate and a liquid electrolyte, the advantages of both technologies can complement each other very well. And finally, you no longer need a separator because the solid substrate does that job. Hence, this could actually be even more than just an interim technology.

Liquid-electrolyte-only batteries have an intrinsically higher risk of overheating and fire. How can designers address that?

Basically, it starts with the cell. You can have flame retardant additive in the electrolyte. Then there's the cell cathode material. For example, iron phosphate is significantly better than nickel-manganese-cobalt in terms of thermal stability. You have the shutdown separators between the anode and cathode, which stop the ion transport and current flow in the cell when heated. But that is not enough. In China, the law requires that drivers have at least five minutes to exit their vehicle when a thermal runaway is detected and before fire and/or venting gas is present in the passenger compartment. However, obviously it shouldn‘t come to that in the first place, which is why the pack design is as important as the battery cell. Heat barriers between cells are applied to prevent a chain reaction within the battery system, so that one defective cell does not set the whole pack on fire. Optimization of the venting gas flow is also critically important. The gases and particles emitted from the cells in thermal runaway should not overheat and destroy sensitive components such as busbars or the battery monitoring system. The gases must be safely discharged from the pack. At the end of the day, it‘s about striking a good balance between safety and energy density. That’s a field where FEV is extremely active in research and development.

You are cooperating with ProLogium on battery development. What was the motivation?

At FEV, we come from complete vehicle and propulsion system development. We understand the requirements for battery cells and battery packs for different applications, that’s one of our core competencies. On top of that, we have more than fifteen years of experience in battery pack development working with a variety of cell suppliers. With our experience in pack design, we are of great benefit to our partners, e.g., in cell dimensioning for optimized cell integration in battery packs and vehicles. What convinced us about ProLogium is their vast experience from research to production, especially with hybrid solid state batteries. They already offer pouch cells that are suitable for automotive use and combine high energy density with safety and reasonable cost. We just tested the recent generation of cells at FEV including fast charging, cycle life and cell safety. The results were very promising. The hybrid solid state technology is scalable; the next cell generation with increased energy densities is already in reach. The background of a battery cell manufacturer with outstanding knowledge in cell chemistry and cell development combined with the experience of an automotive engineering company with deep understanding of battery system development and testing complements each other perfectly. So, this is a partnership that can take us both a long way.

Interview: Gernot Goppelt


Q&A